

AN EVALUATION OF
INTERSECTION ILLUMINATION

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by
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PURDUE UNIVERSITY
LAFAYETTE INDIANA

Final Report

AN EVALUATION OF INTERSECTION ILLUMINATION

TO: K. B. Woods, Director
Joint Highway Research Project

September 27, 1963

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File No: 8-4-14
Project No: C-36-17N

Attached is a Final Report entitled "An Evaluation of Intersection Illumination". This report has been authored by Mr. John M. Wright, Graduate Assistant on our staff, under the direction of Professor J. C. Oppenlander. The report was also used by Mr. Wright as his Thesis for the MSCE degree.

This research was initiated in 1959. Data were collected at that time of travel characteristics at two intersections, one of which had experience as a dangerous intersection while the other was considered to be relatively safe. Two stages of improvement occurred at each location. The first of these stages provided good delineation at each intersection while the later stage provided illumination. Data on travel characteristics and accidents were collected and analyzed for each condition. A previous report included a comparison of the before condition with the after delineation condition. This report includes a comparison of the before, after delineation and after illumination conditions.

This report also includes an economic analysis of delineation and illumination for those two intersections. An apparent relationship between average nighttime volume and the benefits from illumination was noted and is discussed.

The report is presented for the record.

Respectfully submitted,

Harold L. Michael
Harold L. Michael, Secretary

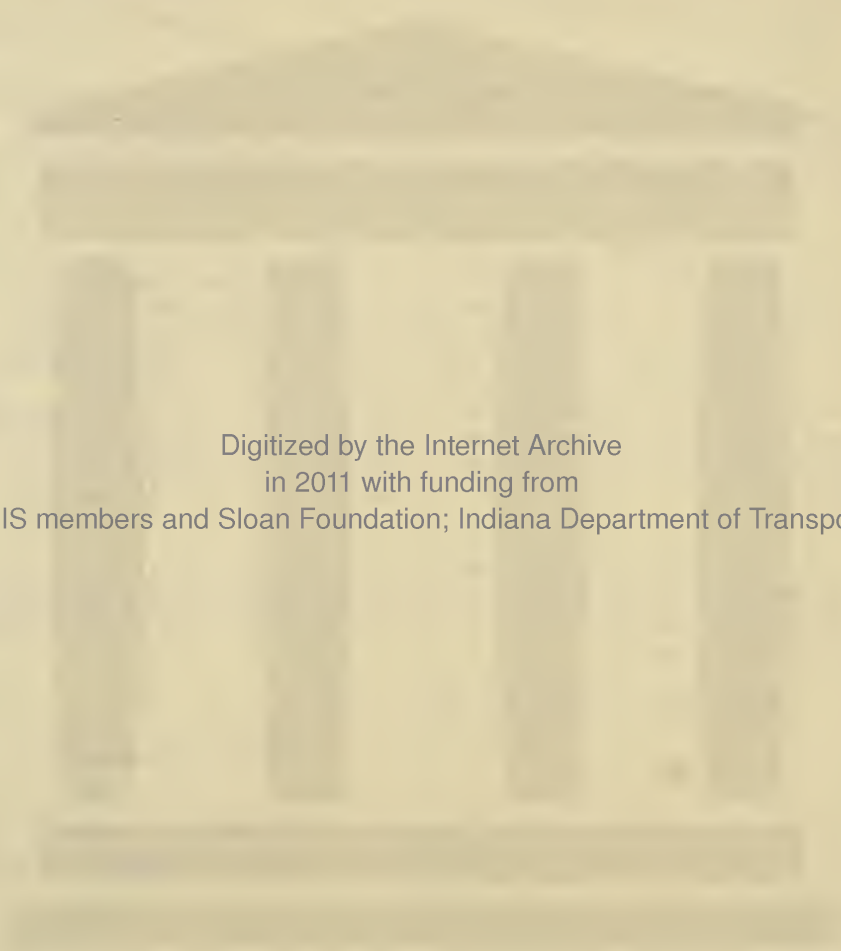
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Final Report

AN EVALUATION OF INTERSECTION ILLUMINATION

by

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Joint Highway Research Project

Project: C-36-17N

File: 8-4-14

Purdue University

Lafayette, Indiana

September 27, 1963

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The author also wishes to express his appreciation to the Joint Highway Research Project whose financial assistance made possible this research project at Purdue University.

Special appreciation is also due my wife, whose encouragement and patience made this work possible.

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ABSTRACT

Wright, John Martin, MSCE, Purdue University, August 1963. An Evaluation of Intersection Illumination. Major Professor: J. C. Oppenlander.

The purpose of this study was to investigate the effects of illumination on certain traffic-stream characteristics at two rural intersections. The first part of this study compared the operational and safety characteristics of these intersections with and without highway illumination. The second part consisted of an economic analysis at both study locations to determine the economic feasibility of intersection illumination.

In 1959 a study was conducted at these two intersections to determine the effect of improved delineation on speed and accident patterns. Incorporating this delineation data into this study allowed comparisons to be made for three periods: before, after delineation, and after illumination.

Individual vehicle speeds were measured using two radar speedmeters, with one operated as a control station. Speeds were obtained at numerous stations located in and adjacent to the study intersections for both daytime and nighttime travel conditions.

Daytime speeds were higher in the after-illumination period than in the before period. Nighttime passenger-car speeds tended to be slightly higher for the after-delineation period than for the before period, although trucks showed no change. At one location, nighttime speeds were higher for the after-illumination period than for the other periods. However, at the other location, nighttime-after-illumination speeds tended to be higher than

before speeds but lower than after-delineation speeds. Control station data indicated the possibility of many of the inconsistencies in the speed patterns being explained by time variations in speed.

The highest quality of flow at one location was evident during the after-illumination period, while at the other location it occurred during the after-delineation period. The before period was always indicative of the poorest quality of flow.

The accident analysis showed a general improvement in the accident situation at both locations for the after-illumination condition. However, at one location, the number of accidents and the accident rate increased slightly over the after-delineation condition.

The economic analysis indicated illumination was more justified at one location, and delineation was more justified at the other location. Illumination at one locations was not economically justified above the delineation because the additional cost of providing illumination was not entirely offset by savings in road-user costs.

The data seems to suggest that illumination is most desirable at one location, while there is less evidence in support of the illumination at the other location. However, this analysis did not take into account comfort, convenience, and ease of travel which may be benefits accruing from the addition of illumination.

An apparent relationship between the average annual nighttime volume and the benefits accruing from illumination was noted in this research investigation. At low nighttime volumes delineation produced the greater benefits, and for larger volumes illumination proved to be more beneficial. The division point between the addition of delineation and that of illumination was approximately 2600 to 2700 vehicles per night.

INTRODUCTION

An important problem confronting highway and traffic engineers is the evaluation of the influence of roadway conditions on traffic-stream characteristics. Many studies have been conducted to determine the effects of these physical features on such variables as speed, lateral placement; headway, lateral clearance, and accidents. These studies have provided valuable information on traffic behavior for more efficient and safe planning, design, and operation of the highway and street systems.

Statistical summaries show that many traffic accidents occur at night when various hazardous and uncomfortable operating conditions exist on the highways. Several circumstances complement this greater nighttime driving hazard. Fatigue and intoxication are more prevalent at night, and a large percentage of nighttime travel consists of long-distance trips. Some drivers operate their vehicles in a careless and irresponsible manner at night. However, the National Safety Council's Committee on Night Traffic Hazards stated that "lowered visibility seems to be the major difference in the hazards of day and night driving" (21)*.

Many techniques and devices are available to improve nighttime visibility. Examples of these aides are:

1. Vehicle headlights,
2. Pavement striping,
3. Delineators,
4. Reflectorized signing,
5. Pavement surfaces of favorable reflectance, and
6. Highway lighting.

* Numbers in parentheses refer to listings in the Bibliography.

The ultimate solution to the problem of night visibility would be to illuminate the highway system at night to the same intensity that exists during daylight. However, this is economically impractical. Present practice involves the illumination of hazardous and critical highway locations, such as sharp curves, important intersections, etc.

Intersections are critical points in our roadway system. In an Ohio study reported by H. R. DeSilva, 25 percent of all rural accidents occurred at intersections (10). A South Carolina study showed that accidents per mile of road were more than 25 times as frequent at intersections as on tangent alinement (10).

The installation of lights at high-accident intersections has reduced nighttime accident rates. This is due to the fact that visibility distance at night is materially increased by fixed illumination. Headlights, even under ideal conditions, fail to provide sight distances of more than 400 ft. This length is shorter than the minimum stopping sight distances required for modern-day highway design.

Speeds are generally increased where highway illumination is provided. C. H. Rex suggested that roadway lighting should increase safe speeds by 10 to 20 mph (27). However, other studies have shown that operating speeds decrease with the addition of illumination. It may be inferred that highway lighting serves both to increase visibility and to alert drivers to the presence of critical locations.

The purpose of this study was to investigate the effects of illumination on certain traffic-stream characteristics at two rural intersections. A comparison of the operation and safety of these intersections was performed under conditions of illumination and no fixed lighting. In addition, an economic analysis at the two study locations was made to determine the economic feasibility of intersection illumination.

In 1959, L. D. Powers investigated the effects of improved delineation on speed characteristics and accidents at these two locations. The results of this illumination study, when compared with the results of the delineation study, provided important information on speed patterns and accident rates under conditions of improved delineation and the combination of lighting and delineation.

The principal purpose of highway illumination is to provide quick, accurate, and comfortable visibility at night. When more comfortable and convenient nighttime travel is provided, more efficient and safe use at night will be made of the large investment in streets, highways, and motor vehicles.

REVIEW OF LITERATURE

The first attempt to provide light for pedestrians and vehicles on the streets was in 1415 when the Mayor of London ordered that a candle be placed in a window facing the street (33). Later in 1694, a law stated that every tenth house on a street was to hang out a lantern in front of the house. Still later in 1716 this was revised to state that all houses should hang lanterns out between the hours of 6:00 p.m. and 10:00 p.m. to provide light for travelers.

Since these first attempts at lighting, much progress has been made in the quality of illumination provided, and many studies have been conducted to determine the effects of this lighting on traffic-stream characteristics. In 1937 C. H. Rex reported on a study in Detroit which found that illumination on 31 miles of main thoroughfares reduced the night-to-day fatality ratio from 7:1 to 1.25:1 (31). In 1948 B. W. Marsh noted similar, if less spectacular, results in New Jersey and San Francisco. In New Jersey fatal accidents on all roads throughout the state during two years following selective lighting of a total of 115 miles were about one-third less than for the preceding two-year period. On the Bayshore Highway, south of San Francisco, accidents per million vehicle miles decreased about one-fourth and fatalities per million vehicle miles more than one-half as a result of highway lighting (21).

In 1957 the Road Research Laboratory made detailed before-and-after studies of lighted highways near London. There was an overall accident

reduction of 35 percent during hours of darkness and an even greater reduction in fatalities and accidents involving pedestrians (4). In France highway lighting has indicated accident reductions as high as 30 percent (4).

A study conducted on the Connecticut Turnpike contrasted continuous lighting with selective illumination located only at interchanges, toll plazas, and service areas. The ratio of night-to-day accidents in the continuously lighted section was 1.01, and that for night-to-day accidents per million vehicle miles of travel was 2.12. Ratios for the sections with selected illumination were 0.94 and 2.00, respectively. This suggests that illumination on a selective basis is as effective as continuous lighting. However, traffic volumes were quite different on the two sections (3).

J. D. Blythe evaluated accident statistics in the Indianapolis area in 1956 and reported that lighting improvements on state highway routes in that city contributed to the reduction in nighttime accidents. For example, before the modernization of the lighting on a two-mile section of U.S. 52 and U.S. 136, there were 60 nighttime accidents in a one-year period. In the following year only 40 nighttime accidents were reported (5). F. D. Wyatt and E. Lozano studied accident data for Michigan Boulevard in Chicago during the period 1947 to 1949 and found that approximately 70 percent of the nighttime accidents were eliminated by improved lighting (36).

In 1962 A. W. Christie reported the findings of an experimental low-cost lighting system for rural highways which consisted of luminaires spaced at 270 ft intervals. This distance is about three times the normal spacing, and seeing is accomplished by silhouette. Nighttime accidents on this test section were reduced by 30 percent with six of seven night accidents in the after period occurring within 250 yd of one end of the test section. Also,

a significant increase in the mean speed was evidenced for one direction of travel (7).

A study in 1939 of a one-mile section of lighted highway near Chagrin Falls, Ohio, showed that the average nighttime speeds, with or without illumination, were lower than the average daytime speeds (12, 20, 35). Average speeds at night were slightly less with illumination than when unlighted. The average speeds were 38.5 mph during the daytime, 36.8 mph with no lighting, and 35.0 mph with illumination. In addition, the percentages of cars traveling faster than 45.5 mph were 20.3, 13.0, and 12.4 percent, respectively.

A research project in New Jersey, reported by O. K. Normann in 1944, on tangent sections of rural highways with few pedestrians and private property entrances and low traffic densities indicated that lighting did not significantly affect travel speeds. However, based on transverse position and clearance between vehicles, the behavior of drivers at night on lighted highways conformed more nearly to their daytime driving practices (24).

Analysis of lighted and unlighted sections of the Connecticut Turnpike in 1958 by A. Taragin and B. M. Rudy indicated that there was no significant difference in average speeds for nine different study conditions involving illumination and delineation. It was also concluded from this study that neither vehicle placement, headway, or lateral clearance were changed to any consistent degree by illumination and/or delineation (34).

An investigation by W. D. Walker on a one-mile section near Chagrin Falls, Ohio, indicated that driver behavior at night with illumination conformed more nearly to that for daytime driving, but behavior without illumination differed greatly from daytime behavior. At night with illumination off the lateral placement of vehicles was 0.5 ft nearer to the center line

of the road. Drivers utilized 57.7 percent of the available passing opportunities during daytime travel conditions. During the nighttime this percentage value was 55.6 for illuminated highways and 38.5 without lighting (35).

D. E. Cleveland conducted a study in 1960 at a rural Y-type intersection in Texas to measure the effect of illumination on driver tension. The galvanic skin reflex, or change in electrical skin resistance, was used to discriminate between the conditions of illumination. Only 80 percent as many tension responses were produced under illumination as compared to no lighting in the intersection. Average travel time was measured through the intersection, and there was found to be no significant difference between travel times for lighted and unlighted conditions (8).

In 1959 J. E. P. Darrell and M. D. Dunnette studied driver performance at a cloverleaf interchange in Minnesota under five illuminated study conditions. Using a carefully developed and conducted interview schedule, the drivers tested stated they were more confident, had less difficulty, and had a better opportunity to do a good job of night driving when visibility was improved by the addition of highway illumination (11).

PROCEDURE

The two locations utilized in this study are described in this section. The speed data were gathered in the Fall of 1962 and the Spring of 1963. Accident data and illumination costs were collected from the Indiana State Highway Commission. The methods of data collection and analysis are also presented in this section.

Study Locations

The locations used for this study were two rural intersections in the State of Indiana (see Figure 1). These particular locations were chosen by L. D. Powers in 1959 when he evaluated the use of highway delineation at these sites. Highway illumination was installed at these intersections in 1961. Therefore, before-and-after studies were performed comparing the existing conditions with the conditions under delineation and illumination.

Location I is the southern junction of routes U.S. 41 and U.S. 52 north of Fowler in Benton County. Both routes are two-lane facilities in the vicinity of this intersection. Travel through this section is complicated by the presence of horizontal curves to the north and south of the intersection with the intersection itself on an eight degree curve. Further hazard arises from the two roadways that merge at a small angle. Sight distances at the ends of the intersection curve are limited because of a high berm and narrow shoulder along the roadway on the inside of the curve.



FIGURE I - STUDY LOCATIONS SHOWING
SPEED MEASUREMENT STATIONS

Immediately prior to the intersection on U.S. 41, a crest vertical curve with 5 percent grades on both sides overpasses railroad tracks. Vehicles from U.S. 41 are required to stop at the junction, while drivers approaching from U.S. 52 need not stop. Driver Approaching the junction from the north on U.S. 52 often experience difficulty in finding their desired route. This confusion results in many drivers stopping their vehicles in the intersection or attempting U-turns around the ends of the traffic islands. Lighting at this location consisted of 400-watt mercury vapor luminaires with an output of 21,000 lumens. The locations of these 22 lamps are shown in Figure 2. These lights were first used on August 1, 1961.

Location II is the junction of U.S. 31 and Indiana State Route 431 north of Carmel in Hamilton County. U.S. 31 is a four-lane, divided highway through the intersection, changing to a two-lane facility southwest of the intersection. The intersection is built to modern design standards with all turning movements channelized and with an acceleration lane provided for traffic merging from State Route 431. The intersection is on a four degree curve with adequate sight distance.

Southeast of the intersection is a crest vertical curve that overpasses railroad tracks. This curve begins after the transition from the four-lane, divided highway to the two-lane facility. Lighting at this location consisted of 250-watt luminaires with an output of 10,000 lumens per lamp. The locations of these 33 lamps are shown in Figure 5. These lights were first put in service on April 19, 1961.

Equipment

All speed data for this study were obtained using Electro-matic radar speedmeters with automobile storage batteries providing power. Two radar meters were in simultaneous operation during all phases of data collection.

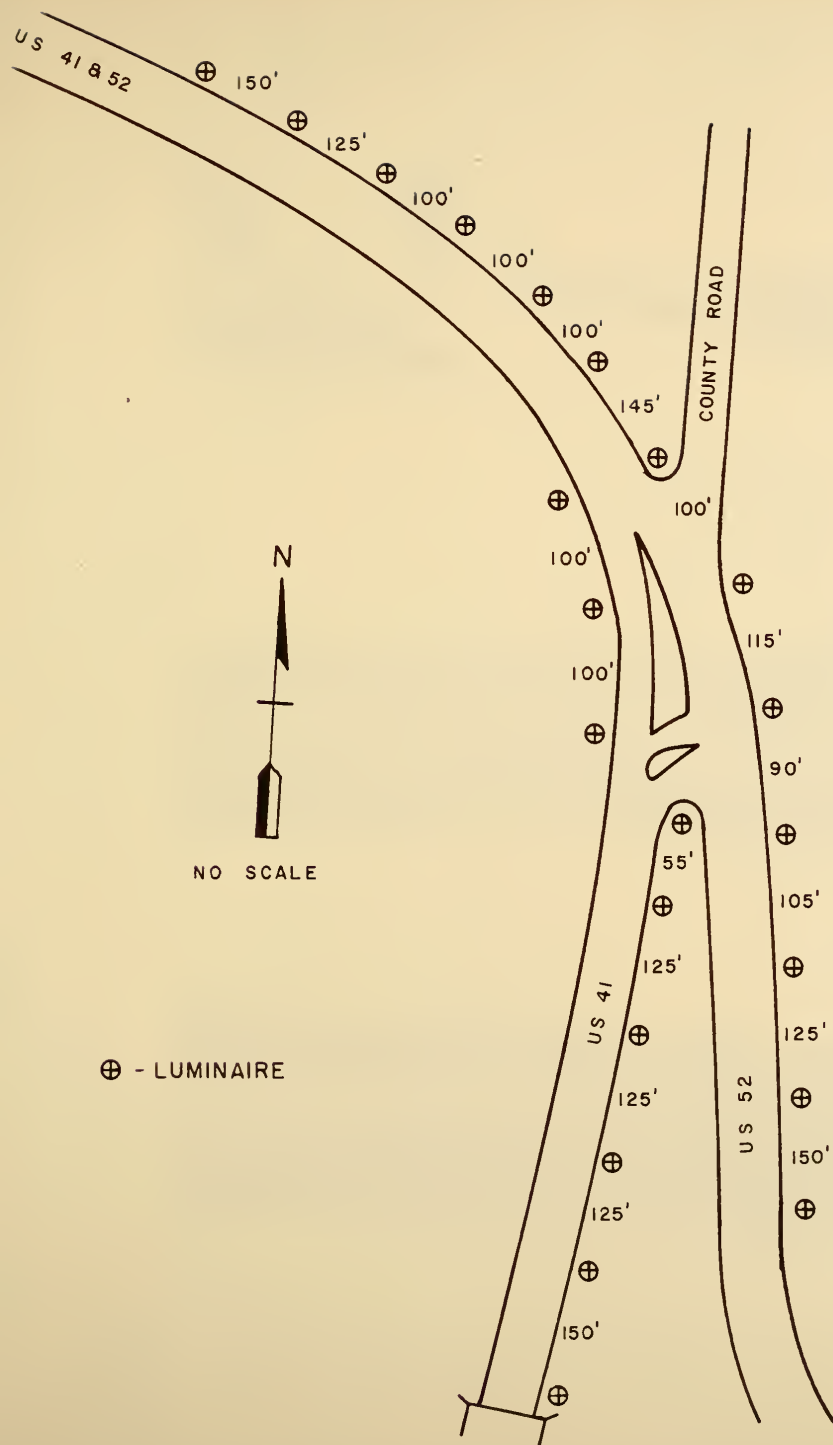


FIGURE 2 - LUMINAIRE UNIT LOCATIONS-LOCATION I



Top: North approach to intersection.
Center: Nose of diverging island, looking south.
Bottom: South curve on U.S. 52.

FIGURE 3 - VIEWS AT LOCATION I



Top: Entrance to intersection from U.S. 52.

Center: Entrance to intersection from U.S. 41, looking north.

Bottom: Center of intersection.

FIGURE 4 - VIEWS AT LOCATION I



Top: Center of intersection, looking north.
Center: Merging area, looking north on U.S. 31.
Bottom: Approach to merging area from S.R. 431.

FIGURE 6-VIEWS AT LOCATION II



Top: U.S. 31, transition from dual to two lane, looking southwest.

Center: Approach to intersection, looking northeast on U.S. 31.

Bottom: Approach to intersection, looking south on U.S. 31.

FIGURE 7-VIEWS AT LOCATION II

One speedmeter was always located at an open highway station approaching the intersection and served as a control station to determine the daily variation in vehicle speeds. Care was taken to render both setups inconspicuous. There was no apparent change in speed under these conditions as traffic approached the speed-measurement stations.

Each meter was placed 3 to 4 ft from the pavement edge to minimize the angle between the meter and the direction of travel. Although the indicator reading represented only a component of the true vehicle speed, any speed inaccuracies were considered negligible for the small angles encountered.

Because radar equipment does not operate properly if the voltage varies more than plus 1.0v or minus 0.5v from the optimum 12v, the battery voltage was checked periodically and maintained within the proper range. The meters were periodically checked with 30, 45, and 60 mph tuning forks to keep the instruments calibrated.

Field Studies

It was necessary to make preliminary surveys at both locations before the actual collection of speed data. Speed-measurement stations were chosen to coincide with those used by L. D. Powers in his delineation study. These stations were used to develop speed patterns through the intersection. Each station was marked with stakes set flush with the ground and tied into existing landmarks. One station was far removed from the intersection on each road leading to the intersection to obtain data representative of open-highway speeds for vehicles approaching and leaving the study site. Other stations were located on the approach, in the center, and on the exit from the intersection for each intersecting roadway. The location of these speed-measurement stations is shown in Figure 1. Information on the range of standard

SPEED STUDY

DATE 3-27-63 TIME 7:30 P.M. OBSERVER LEMINGLOCATION I-j WEATHER CLEAR-DRY

PASSENGER CARS			TRUCKS	
SPEED	NORTH	SOUTH	NORTH	SOUTH
80				
79				
78				
77				
76				
75				
74				
73				
72				
71				
70				
69				
68				
67				
66				
65				
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36				
35				
34				
33				
32				
31				
30				

SAMPLE FIELD DATA SHEET

FIGURE 8

deviations as found by L. D. Powers in his delineation study was used in determining the sample size that was required for estimating the mean speed within plus or minus 1 mph at a confidence level of 95 percent. Passenger-car and truck standard deviations were estimated to be 6.0 and 4.0 mph, respectively. The required sample size was determined to be 138 for cars and 62 for trucks. These numbers were rounded off to 140 cars and 60 trucks for the field studies.

Radar meters were positioned to measure speeds as the vehicles passed the study locations. The field crew consisted of two data recorders with one at each speedmeter. At night each recorder was equipped with a flashlight, and precaution was taken to shield the light from the view of oncoming drivers.

Mathematical Evaluations

The data collected in this investigation were analyzed to evaluate the effects of delineation and illumination on traffic flow. The LGP-30 Computer, available in the School of Civil Engineering, was used to process the speed observations. A program was written to calculate the mean speed, standard deviation, 85th-percentile speed, pace limits, and percentage in the pace for each speed-measurement station. These values were analyzed to determine whether observed differences in parameters were statistically significant.

Accident data were obtained from the Indiana State Police files in Indianapolis. These accident data were accumulated at each intersection for three periods: before delineation, after delineation, and after illumination. At Location I, three 19-month periods were studied: the before-delineation period being from February 1, 1957, to August 31, 1958, the after-delineation period being from January 1, 1960, to July 31, 1961, and

the after-illumination period being from August 1, 1961, to February 28, 1963. At Location II, three 22-month periods were studied: the before-delineation period being from November 1, 1956, to August 31, 1958, the after-delineation period being from June 1, 1959, to March 31, 1961, and the after-illumination period being from May 1, 1961, to February 28, 1963.

A quality index of traffic flow was calculated for each study period. The factors which determine the quality of traffic flow are the average speed and the frequency and magnitude of speed changes. Average speed determines the time of travel, which we desire to minimize. The higher the average speed, the higher is the quality of traffic flow. The magnitude and frequency of speed changes are undesirable factors. The quality of traffic flow, therefore, decreases as speed changed (both magnitude and frequency) increase. The quality index developed by B. D. Greenshields is written as the following equation (15).

$$Q' = \frac{S}{\Delta_s \sqrt{f}}$$

where Q' = quality index

S = average speed, mph

Δ_s = absolute sum of speed changes per mile, mph

f = number of speed changes per mile

Because this study dealt with spot speeds at several stations through the intersection, it was necessary to modify the above index to make it applicable to this investigation. The frequency of speed changes was eliminated from the above equation because it was impossible to trace the path of each individual vehicle through the intersection. The quality index was revised to the form indicated below.

$$Q = \frac{S}{ds}$$

where Q = study quality index

S = average speed, mph

ds = total change in speed through the intersection,
mph

Average speed between any two successive stations was determined as a uniform change in speed between the stations. The average speed through the intersection, S, was determined by a weighted average of the average speeds between each two successive stations on the basis of distance. The absolute total change in speed, ds, was obtained by summing the differences in the mean spot speeds between successive stations.

The accident data were classed according to time and severity of the accidents. Accident rates per million vehicle miles were calculated for each period under both daytime and nighttime travel conditions. Vehicle volumes used in the calculations were obtained from the Planning Division of the Indiana State Highway Commission. Accident costs were calculated with the following unit costs:

1. Property damage only - \$300 per involvement,
2. Personal injury - \$1600 per person, and
3. Fatality - \$30,000 per person (19).

An economic analysis was conducted at each intersection to determine the feasibility of delineation and illumination. The benefit-cost ratio is a method of analysis where the road-user costs and the costs of the improvement are determined for each alternate. These amounts are expressed as the quotient of the cost differences in the following manner.

$$\text{Benefit-cost ratio} = \frac{\text{Difference in road-user costs}}{\text{Difference in highway costs}}$$

$$= \frac{R - R_1}{H_1 - H}$$

where

R = total road-user cost for the basic condition

R_1 = total road-user cost for the improvement

H = total highway cost for the basic condition

H_1 = total highway cost for the improvement

Road-user costs for this study included time, accident, and operating costs. Operating costs accounted for fuel, tires, oil, maintenance and repair, and depreciation. Values for time and operating costs used in this study were obtained from Road User Benefit Analyses for Highway Improvement (1). Accident costs were procured from An Economic Evaluation of Traffic Flow at Various Speeds by J. C. Marcellus (19). The Indiana State Highway Commission provided illumination and delineation costs.



RESULTS

The results presented in this section include speed and accident patterns, traffic-flow quality indices, speed variations at control stations, and benefit-cost ratios. An investigation of the effects of nighttime volume on the traffic-flow quality indices and benefit-cost ratios was also undertaken to evaluate the effectiveness of highway delineation and illumination.

Analysis of Zones

Two parameters were used to describe the speed distribution, magnitude and dispersion. Parameters of magnitude are mean speed, 85th-percentile speed, and 10-mph pace. Parameters of dispersion are standard deviation and percentage in the pace. The spot speeds were assumed to be normally distributed. This assumption is upheld by previous research studies.

The first phase of the analysis was an investigation of the observed changes in means and variances at each station for one-day and three-night, before-and-after studies. These four before-and-after studies were:

1. Day-before and day-after,
2. Night-before and night-after delineation,
3. Night-before and night-after illumination, and
4. Night-after delineation and night-after illumination.

Mean speeds and variances were analyzed statistically to determine whether the observed differences in the before-and-after studies were due to chance variation or to actual changes in the parameters. A summary of the changes in these statistics is given in Tables 1 to 3. The classes labeled higher,

TABLE 1

NUMBER OF STATIONS EXPERIENCING CHANGES IN MEANS AND VARIANCES

Location I - Passenger Cars						
Stations*	Means			Variances		
	Lower	No Change	Higher	Lower	No Change	Higher
DAYTIME BEFORE - DAYTIME AFTER						
OHA	1	1	1	1	2	0
E&E	2	2	5	1	8	0
COI	1	2	4	2	5	0
NIGHTTIME, BEFORE - NIGHTTIME, AFTER DELINEATION						
OHA	0	3	0	0	3	0
E&E	0	2	7	2	6	1
COI	2	3	2	0	5	2
NIGHTTIME, BEFORE - NIGHTTIME AFTER ILLUMINATION						
OHA	1	1	1	0	3	0
E&E	0	2	7	2	7	0
COI	0	0	7	1	6	0
NIGHTTIME, AFTER DELINEATION - NIGHTTIME, AFTER ILLUMINATION						
OHA	1	2	0	1	2	0
E&E	2	4	3	1	8	0
COI	0	2	5	2	5	0

* LEGEND for Tables 1 to 3:

OHA: Open highway stations approaching the intersection

E&E: Stations at the entrance to and exit from the critical area of the intersection

COI: Stations at or near the center of the intersection

Higher: Significantly higher at 5-percent level

No Change: No significant difference at 5-percent level

Lower: Significantly lower at 5-percent level

TABLE 2

NUMBER OF STATIONS EXPERIENCING CHANGES IN MEANS AND VARIANCES

Location I - Trucks						
Stations*	Means			Variances		
	Lower	No Change	Higher	Lower	No Change	Higher
DAYTIME BEFORE - DAYTIME AFTER						
OHA	1	1	1	0	2	1
E&E	1	4	4	1	7	1
COI	1	1	5	0	6	1
NIGHTTIME BEFORE - NIGHTTIME AFTER DELINEATION						
OHA	0	3	0	0	3	0
E&E	4	5	0	2	6	1
COI	0	5	2	1	4	2
NIGHTTIME BEFORE - NIGHTTIME AFTER ILLUMINATION						
OHA	0	1	2	0	3	0
E&E	0	5	4	0	8	1
COI	0	2	5	1	4	2
NIGHTTIME AFTER DELINEATION - NIGHTTIME AFTER ILLUMINATION						
OHA	1	0	2	0	3	0
E&E	0	2	7	0	9	0
COI	1	2	4	0	7	0

* See Legend, page 25

TABLE 3

NUMBER OF STATIONS EXPERIENCING CHANGES IN MEANS AND VARIANCES

Location II - Passenger Cars						
Stations*	Means			Variances		
	Lower	No Change	Higher	Lower	No Change	Higher
DAYTIME BEFORE - DAYTIME AFTER						
OHA	0	1	1	2	0	0
E&E	2	1	1	3	1	0
COI	2	2	3	1	6	0
NIGHTTIME BEFORE - NIGHTTIME AFTER DELINEATION						
OHA	0	1	1	1	1	0
E&E	0	3	1	1	2	1
COI	1	1	5	0	7	0
NIGHTTIME BEFORE - NIGHTTIME AFTER ILLUMINATION						
OHA	0	1	1	2	0	0
E&E	1	3	0	2	2	0
COI	0	4	3	2	5	0
NIGHTTIME AFTER DELINEATION - NIGHTTIME AFTER ILLUMINATION						
OHA	0	1	1	0	2	0
E&E	1	2	1	2	2	0
COI	4	2	1	3	4	0

* See Legend, page 25

no change, and lower indicate the direction of change as an increase, lack of change, or decrease, respectively. Higher or lower classes denoted those stations where the statistical test evidenced an actual increase or decrease in the parameter at the five percent level of significance.

Those rows labeled "open-highway-approaching" consisted of the changes in statistics at stations which were located at a sufficient distance from the sites so that no change should have occurred among the nighttime phases due to delineation or illumination. "Entrance and exit" referred to those stations at the approach to or exit from the critical area of the intersection. "Critical" stations were those at or near the center of the intersection.

Inspection of these tables of changes in means and variances showed a definite increase in daytime speeds from the before-to-after period, especially at Location I. The percentages in the higher, no change, and lower groups were equal for the open-highway-approaching stations. Ratios of increases over decreases of two to one with less than one-third of the stations showing no change were observed at the other stations.

Variances changed little for the day-before, day-after study. Passenger-car variances did not increase, but decreases in variance were noted at several stations, particularly at Location II. Three of the 19 variances for truck speeds increased with two located in the critical zone. One decrease in truck speed variance was noted.

For the night-before, night-after-delineation phase, few changes in mean speeds of passenger cars were noted. Exceptions were found at the entrance-and-exit zone of Location I and at the critical zone of Location II, where the mean values increased between the two periods. Truck mean

speeds at Location I changed very little except at approximately one-half of the stations located in the entrance-and-exit zone.

Variances for the night-before, night-after delineation study showed little consistency. Several increases and decreases were observed for both passenger cars and trucks.

A large percentage of the mean speeds in the entrance-and-exit and critical zones increased for the night-before, night-after illumination study. At Location I passenger car speeds increased at 14 of the 16 stations. More stations in the critical zone showed increases in mean speeds than in any other zone. This tendency may indicate that the illumination was a definite improvement in aiding drivers in following their desired route through the intersection with the least inconvenience.

Variances in speeds of passenger cars for the night-before, night-after illumination phase were slightly lower. At Location II decreases in variance were noted at six of the 13 stations. Truck variances were not significantly different for the two conditions.

For the night-after-delineation, night-after-illumination phase, the two locations exhibited different characteristics in the changes in means for passenger cars. At Location I, five of seven stations in the critical zone had increases in mean speed. However, at Location II four of seven stations in the critical zone showed decreases in mean speed. It appears that the illumination at Location I is aiding drivers in finding their way through the intersection while at Location II it is causing drivers to reduce their speed near the center of the intersection. In addition, the night volume at Location I was one-third to one-half greater than the night volume at Location II. Truck mean speeds at Location I increased at 13 of the 19 stations.

Variances in speeds of passenger cars for the night-after-delineation, night-after-illumination phase decreased slightly at Location II for the entrance-and-exit and critical zones. Truck speed variances did not significantly change at any station.

Analysis of Individual Locations

The speed profiles by direction are shown in Figures 10 to 15 for each location. Acceleration and deceleration patterns were inferred from these profiles although these are plots of the mean spot speeds. This discussion was confined to a comparison of the three nighttime phases.

Location I (Figures 10 to 13)

Northbound (passenger cars): The night-before and night-after delineation profiles for U.S. 41 and U.S. 52 were very similar. An exception was at the curve south of the intersection on U.S. 52 where night-after-delineation speeds decreased. An increased acceleration rate led to higher speeds at both stations f and g, located north of the intersection, for the after-delineation period. The night-after illumination profile was significantly higher at all stations than the night-before speed profile. However, at station j on U.S. 41 approaching vehicle speeds were about the same for both study periods.

Speeds at the open-highway approaching station on U.S. 52 were approximately equal for the night-after delineation and night-after illumination profiles. Due to decreased deceleration rates night-after illumination speeds were higher through the south curve. Speeds were approximately equal for the remainder of the stations. The only exception was at e in the critical area of the intersection where night-after illumination speeds increased.

SPEED PROFILES LOCATION 1 - DAYTIME PASSENGER CARS

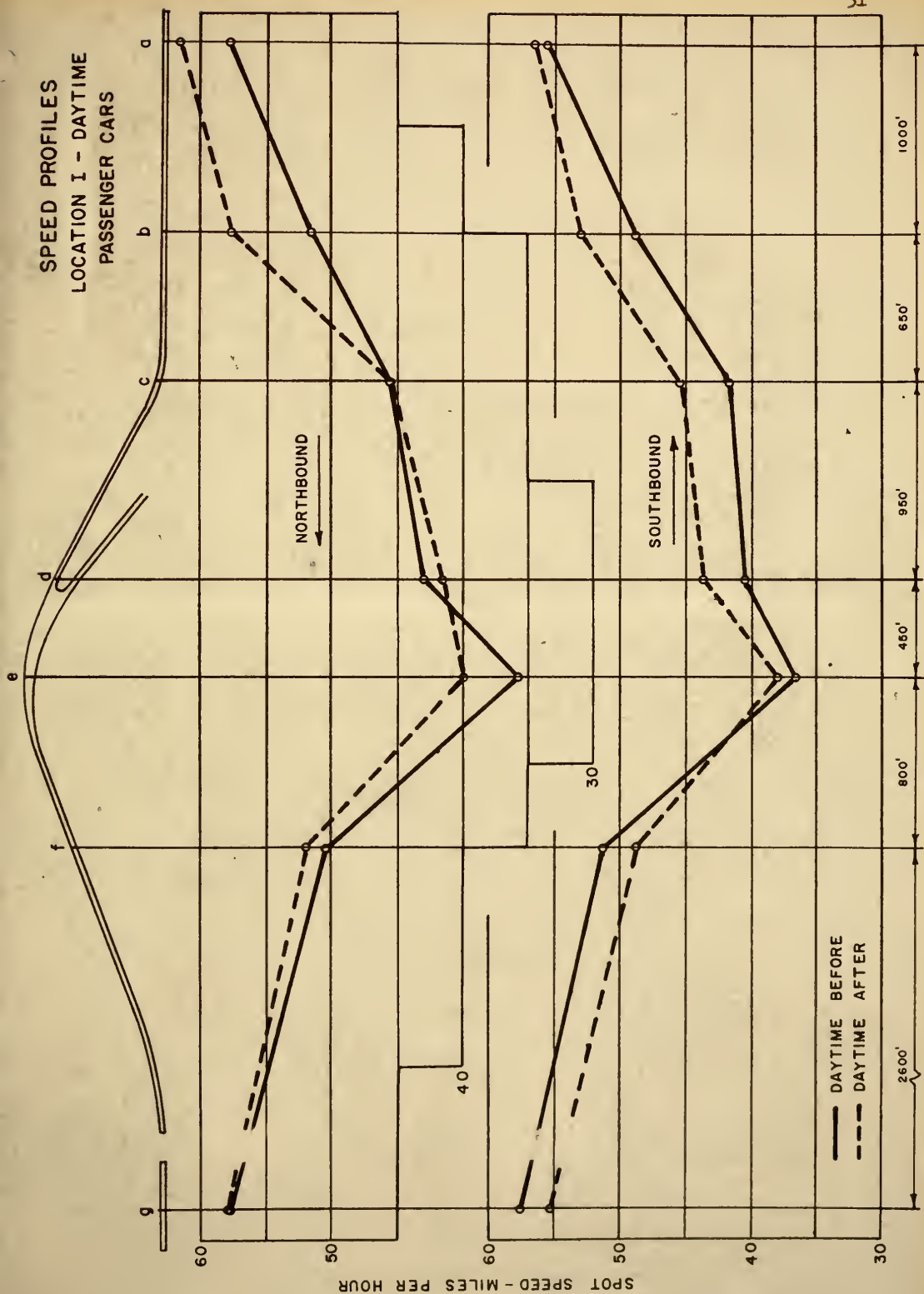
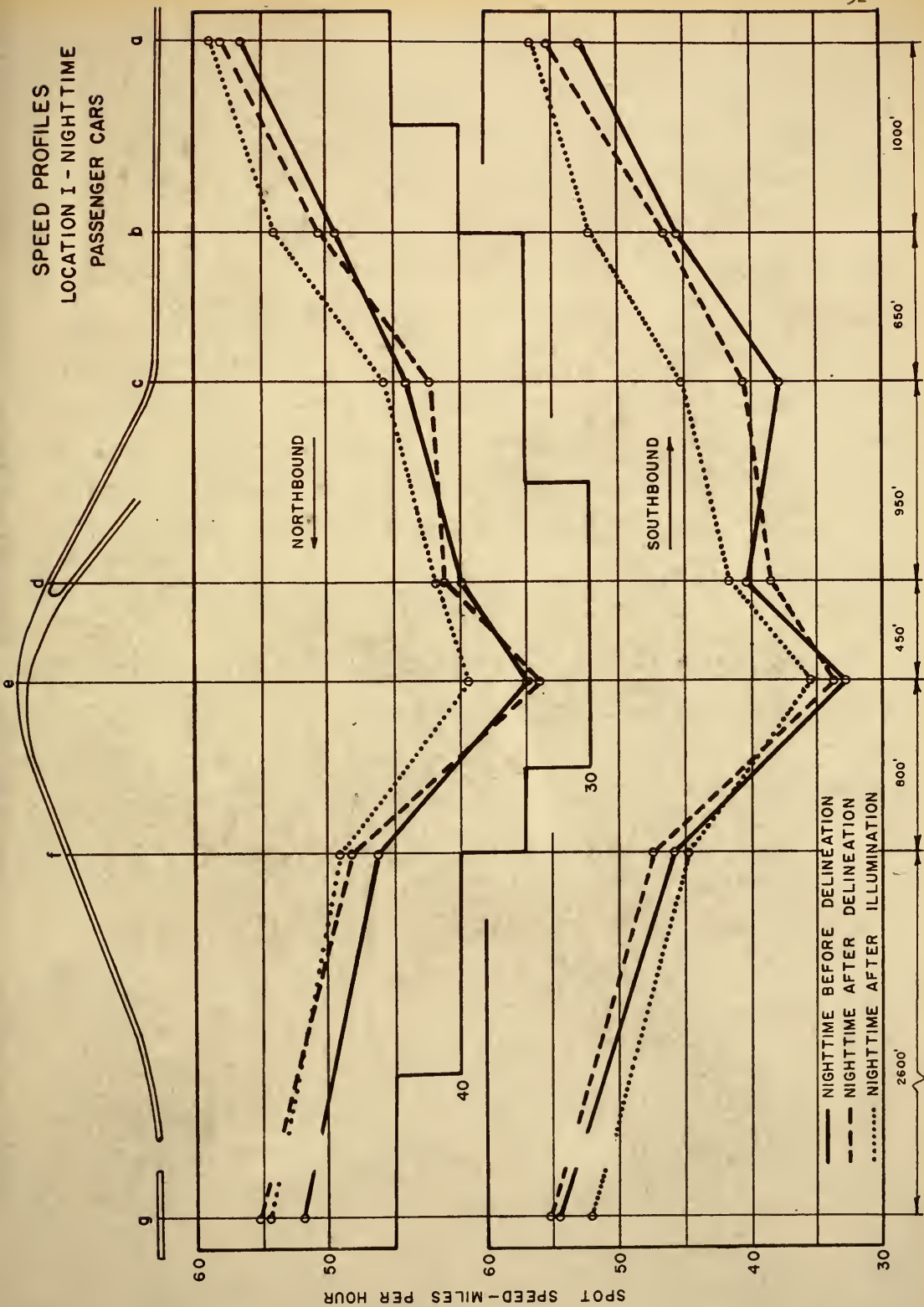


FIGURE 10



APPROXIMATE DISTANCES BETWEEN STATIONS

FIGURE II

Southbound (passenger cars): The approach speeds of vehicles on U.S. 52 were approximately equal for the night-before and night-after delineation phases. However, delayed deceleration resulted in higher night-after delineation speeds north of the intersection. Vehicles in the night-after delineation period decelerated rapidly on approaching the north edge of the critical area, and speeds were equal for both periods. Due to an irregular acceleration pattern in the night-before period, speeds decreased on leaving the south edge of the intersection but increased through the south curve. There was no difference in speeds for the two periods as vehicles accelerated toward open-highway speeds. Night-after delineation speeds were higher than night-before speeds at the open-highway-leaving station. Speeds of vehicles turning onto U.S. 41 increased during the night-after delineation period.

Vehicle speeds at the open-highway-approaching station were lower in the after-illumination period than in the night-before period, but due to decreased deceleration no change in speeds at station f north of the intersection was apparent. Speeds were higher in the night-after illumination period than in the night-before period at all other stations on U.S. 52.

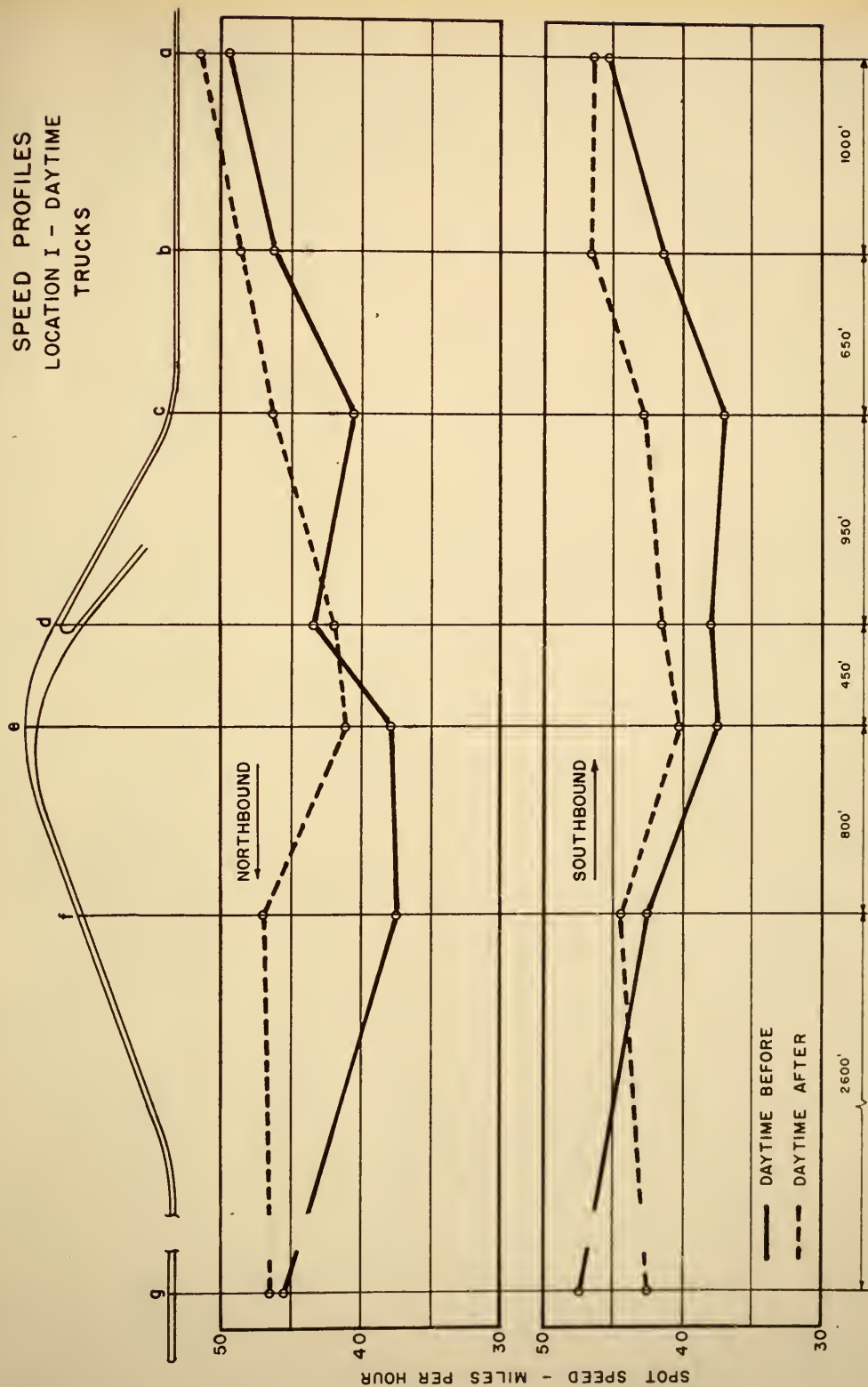
Vehicle speeds were lower for both the open-highway-approaching station and the station north of the intersection for the after-illumination period when compared to the after-delineation period. Due to decreased deceleration at the north edge of the intersection, vehicle speeds increased at all stations through the intersection and on U.S. 52 in the night-after illumination period. Speeds of vehicles turning onto U.S. 41 decreased in the night-after illumination period.

Northbound (trucks): A significant difference in speeds was noted at only one station for the night-before and night-after-delineation study. Night-after-illumination speeds were generally higher than night-before speeds. Exceptions included the station north of the intersection and the open-highway-leaving station where no change was noted. Night-after-illumination speeds were generally higher than night-after-delineation speeds. However, there were no changes in vehicle speeds at one station south of the intersection and at another station north of the intersection.

Southbound (trucks): Speeds were mostly unchanged on U.S. 52 for the night-before, night-after-delineation comparison. At the south curve the night-after-delineation speeds were higher than the night-before speeds. Night-after-delineation speeds decreased at the open-highway-leaving station south of the intersection. Truck speeds increased near the intersection for vehicles turning onto U.S. 41. No change in speeds was observed between the night-before and night-after-illumination phases as vehicles approached the intersection. However, due to an increased acceleration rate, truck speeds increased on U.S. 52 after leaving the intersection. There was no change in truck speeds as vehicles turned onto U.S. 41.

Speeds were lower at the open-highway-approaching station for the night-after-illumination period as compared to the night-after-delineation period. Because of decreased deceleration, there was no change in the speeds as vehicles neared the intersection. Rapid accelerations on leaving the intersection caused after-illumination speeds to be higher for all stations south of the intersection on U.S. 52. Speeds of trucks turning onto U.S. 41 decreased in the night-after-delineation period.

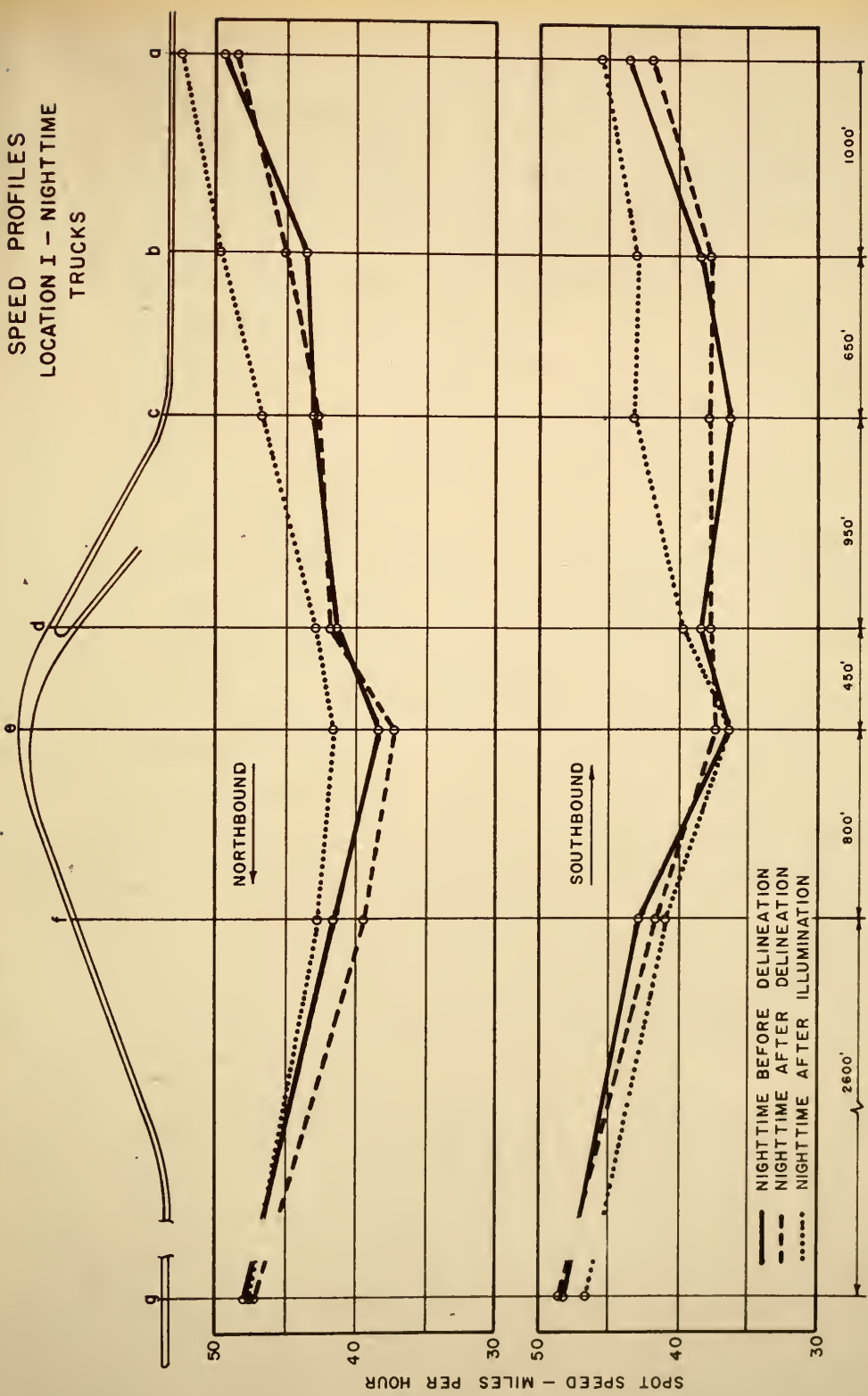
SPEED PROFILES LOCATION I - DAYTIME TRUCKS



APPROXIMATE DISTANCES BETWEEN STATIONS

FIGURE 12

SPEED PROFILES LOCATION I - NIGHTTIME TRUCKS



APPROXIMATE DISTANCES BETWEEN STATIONS

FIGURE 13

Location II (Figures 14 and 15)

Northbound (passenger cars): No significant difference was evident in vehicle speeds at the open-highway-approaching and leaving stations on U.S. 31 for the night-before and night-after-delineation periods. Decreased deceleration caused higher speeds through the intersection. A reduction in speeds was observed north of the intersection for the night-after-delineation period. Cars from State Route 431 approached the intersection at the same speed for the two periods, but the night-after-delineation speeds increased in the merging area.

No change was noted in the speeds on U.S. 31 for the night-before, night-after-illumination period. Cars from S.R. 431 approached the intersection at lower speeds during the night-after-illumination period, but night-after-illumination speeds were higher at the merging area than night-before speeds.

For the night-after delineation and night-after illumination phase, open-highway-approach speeds were statistically equal. Increased deceleration reduced night-after-illumination speeds through the intersection. Night-after-illumination speeds increased north of the intersection. Speeds were lower approaching the intersection from S.R. 431 for the night-after illumination period, and increased acceleration caused equal speeds at the merging area.

Southbound (passenger cars): An increase in speeds was noted at all but one location when delineation was added. Night-after illumination speeds were higher than night-before speeds on the approach to the intersection and through the intersection. There was no change in speeds south of the intersection for the night-before and night-after illumination phases.

SPEED PROFILES
LOCATION II - DAYTIME
PASSENGER CARS

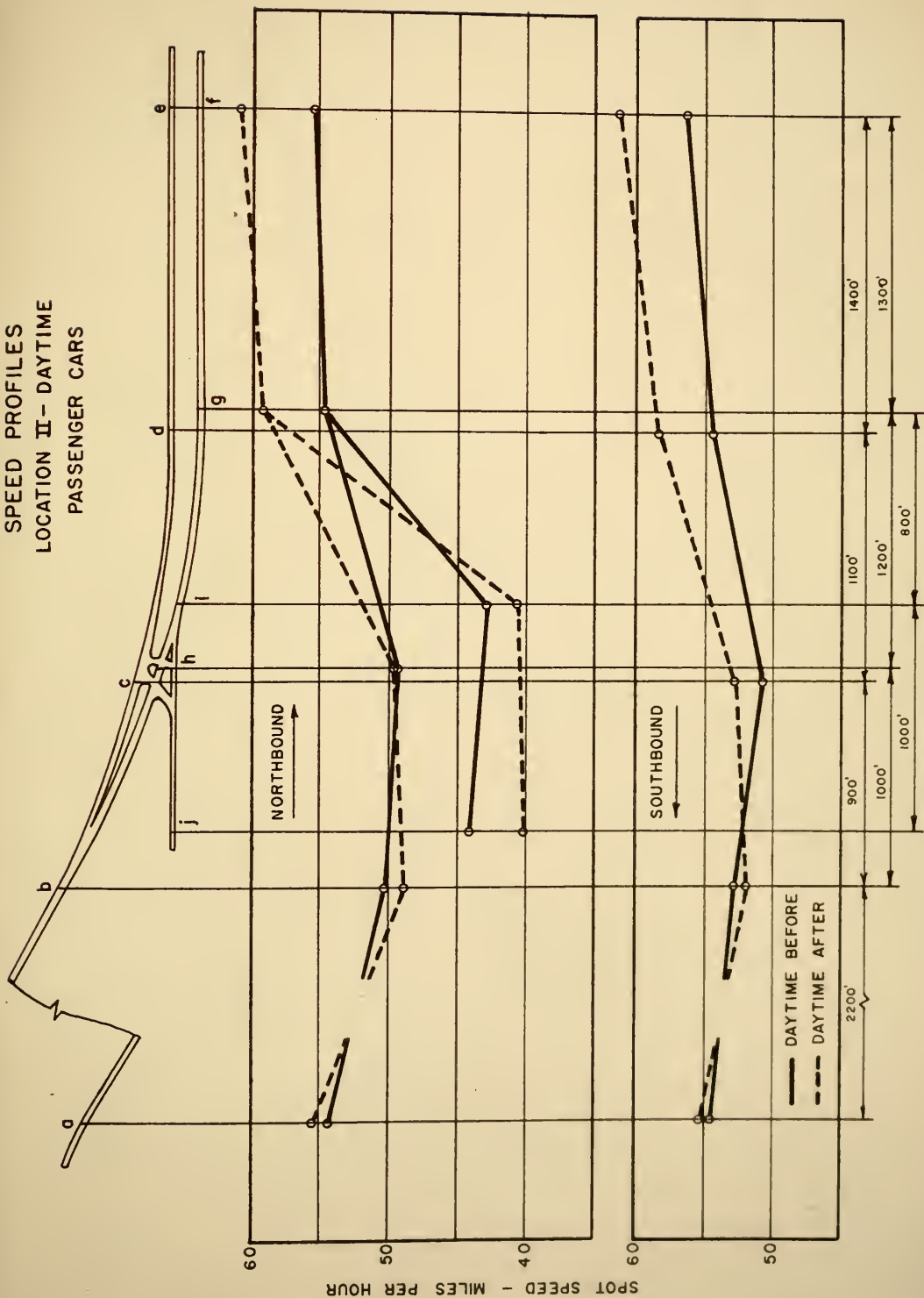


FIGURE 14

SPEED PROFILES
LOCATION II - NIGHTTIME
PASSENGER CARS

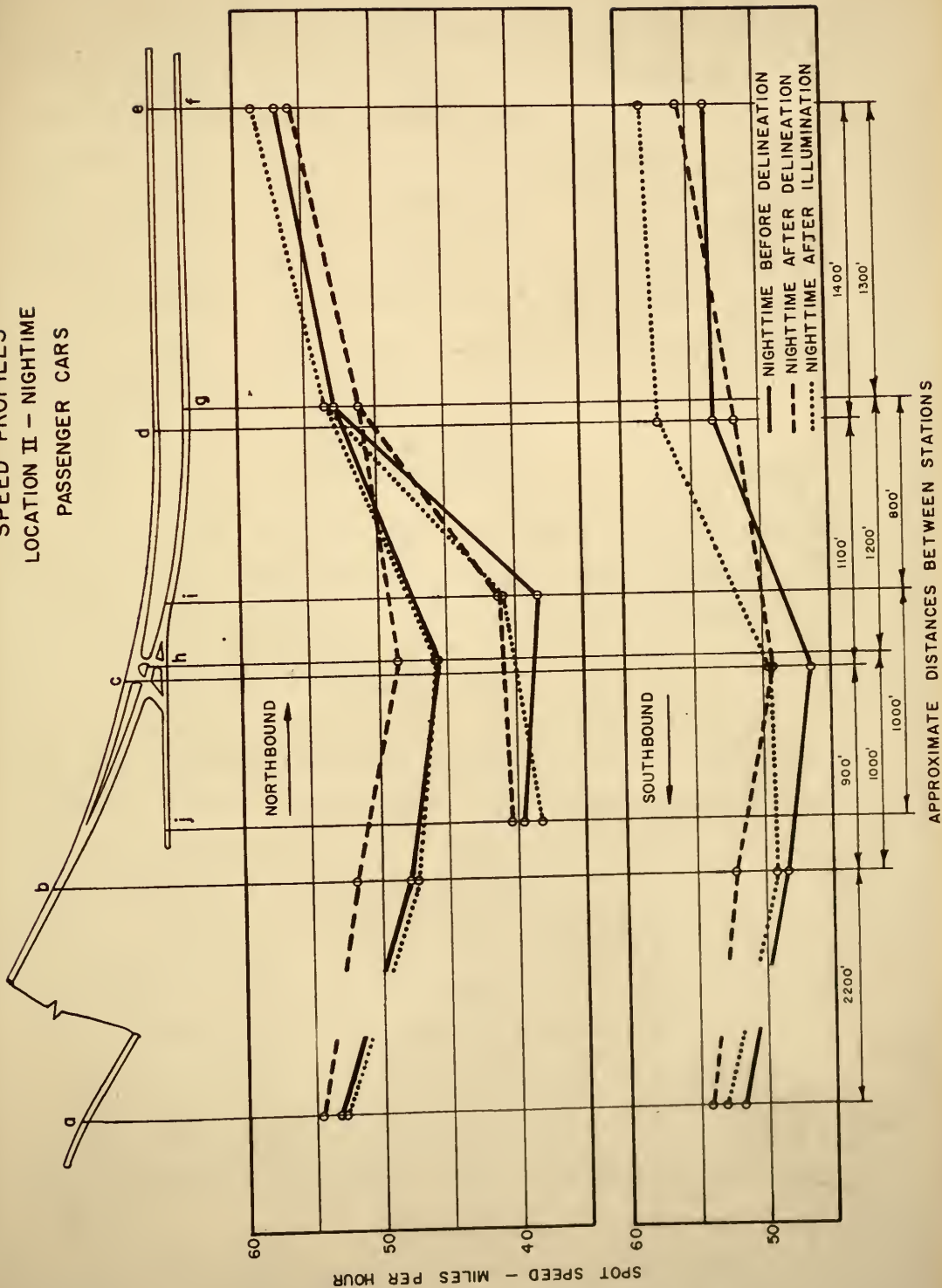


FIGURE 15

Although night-after-illumination speeds were higher than night-after-delineation speeds for vehicles approaching the intersection, increased deceleration produced equal speeds through the intersection. Delayed acceleration in the night-after-illumination period led to lower speeds south of the intersection. Night-after-illumination speeds then increased and no difference in speeds was observed at the open-highway-leaving station.

At Location II the percentage of trucks in the traffic stream was too small to obtain an adequate sample size for statistical analysis. Therefore truck speeds were not recorded at this location.

Accident Analysis

Tables 4 to 6 and Figures 16 to 19 present a summary of the accident data at the two locations for each condition of study. Three 19- and three 22-month periods were studied at Locations I and II, respectively.

Location I

Examination of Table 4 shows that daytime accidents remained fairly constant at Location I, but nighttime accidents decreased with each successive period considered. There were nine nighttime accidents in the night-before period, seven in the night-after-delineation period, and only three in the night-after-illumination period. A large percentage of these accidents occurred in the area where northbound traffic on U.S. 41 entered U.S. 52. These accident locations are illustrated in Figure 17.

The daytime accident rate (accidents per million vehicle miles of travel) decreased at Location I during the day-after-delineation period when compared to the day-before period. There was a slight increase in the

TABLE 4
ACCIDENT SEVERITY

Condition	Day			Night		
	PD	I	F	PD	I	F
<u>Location I</u>						
Before	12	2	0	5	4	0
After Delineation	11	0	0	6	0	1
After Illumination	12	1	0	2	1	0
<u>Location II</u>						
Before	4	1	0	3	1	1
After Delineation	6	3	1	2	2	0
After Illumination	8	2	0	4	2	0

PD: Property damage only accident

PI: Personal injury accident

F: Fatal accident

TABLE 5

ACCIDENT RATES
(Accidents per million vehicle miles)

Condition	Day	Night	Total
<u>Location I</u>			
Before	4.12	3.97	4.06
After Delineation	2.85	2.72	2.80
After Illumination	3.02	1.04	2.23
<u>Location II</u>			
Before	2.17	5.05	3.03
After Delineation	3.65	3.41	3.58
After Illumination	3.16	4.42	3.54

TABLE 6
ACCIDENT COSTS

Condition	Day	Night	Total
<u>Location I</u>			
Before	\$ 8,400	\$14,300	\$22,700
After Delineation	\$ 3,300	\$31,800	\$35,100
After Illumination	\$ 5,200	\$ 2,200	\$ 7,400
<u>Location II</u>			
Before	\$ 6,000	\$37,300	\$43,300
After Delineation	\$36,600	\$ 5,400	\$42,000
After Illumination	\$ 5,600	\$ 4,400	\$10,000

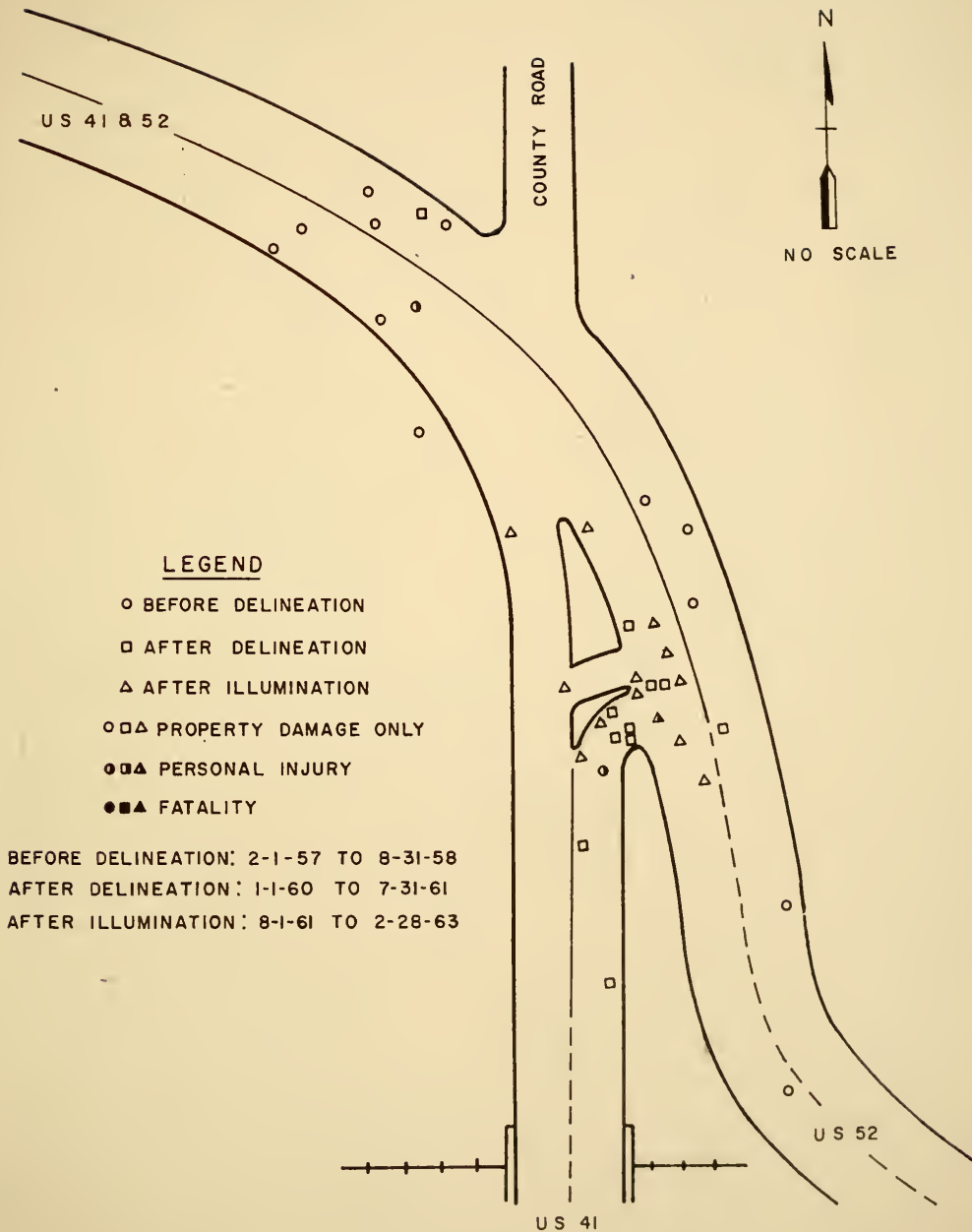


FIGURE 16 - ACCIDENT RECORD AT LOCATION I - DAYTIME

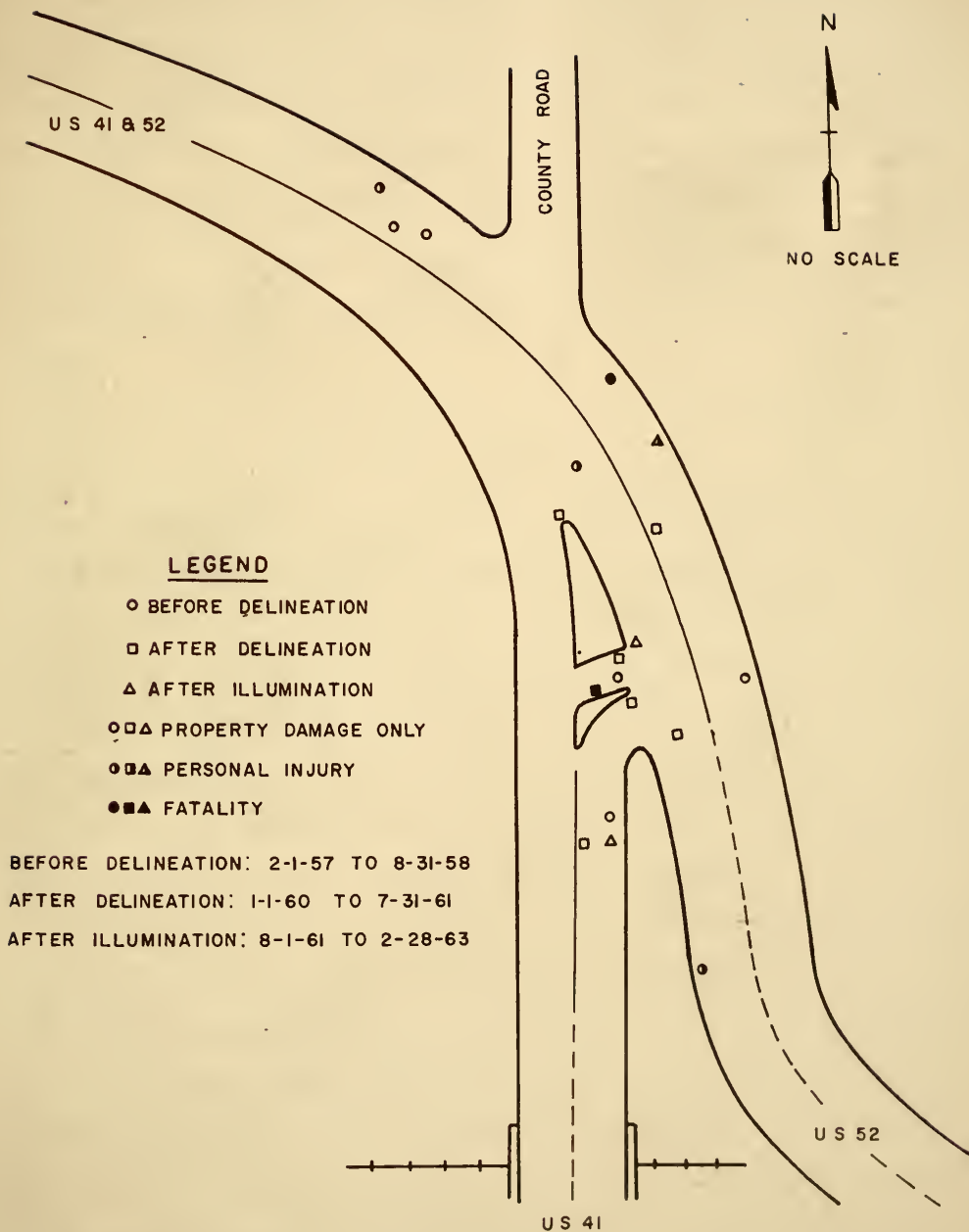


FIGURE 17 - ACCIDENT RECORD AT LOCATION I - NIGHTTIME

accident rate during the day-after-illumination period. The nighttime accident rate for the after-delineation period was lower than for the before period. The night-after-illumination accident rate was less than either the night-before or night-after-delineation accident rate. The costs of day-time accidents at Location I were 8400, 3300, and 5200 dollars for the day-before, day-after delineation, and day-after-illumination periods, respectively. The nighttime costs for the same periods were 14,300, 31,800, and 2200 dollars.

Location II

At Location II there were ten daytime accidents in both the after-delineation and after-illumination phases and only five daytime accidents in the before period (Table 4). The nighttime accidents were fairly constant with five in the before period, four in the after-delineation period, and six in the after-illumination period. Most of the accidents were caused by turning movements in the intersection as illustrated in Figure 19. Several accidents (none in the after-illumination period) occurred south of the intersection at the transition from four to two lanes.

The daytime accident rates for the after-delineation and after-illumination periods were higher than for the before period at Location II. However, the day-after-illumination rate was lower than the day-after-delineation rate. The nighttime rates showed an opposite pattern. Both the night-after-delineation and night-after-illumination periods had lower accident rates than the night-before period. The night-after-delineation rate was less than the night-after-illumination rate.

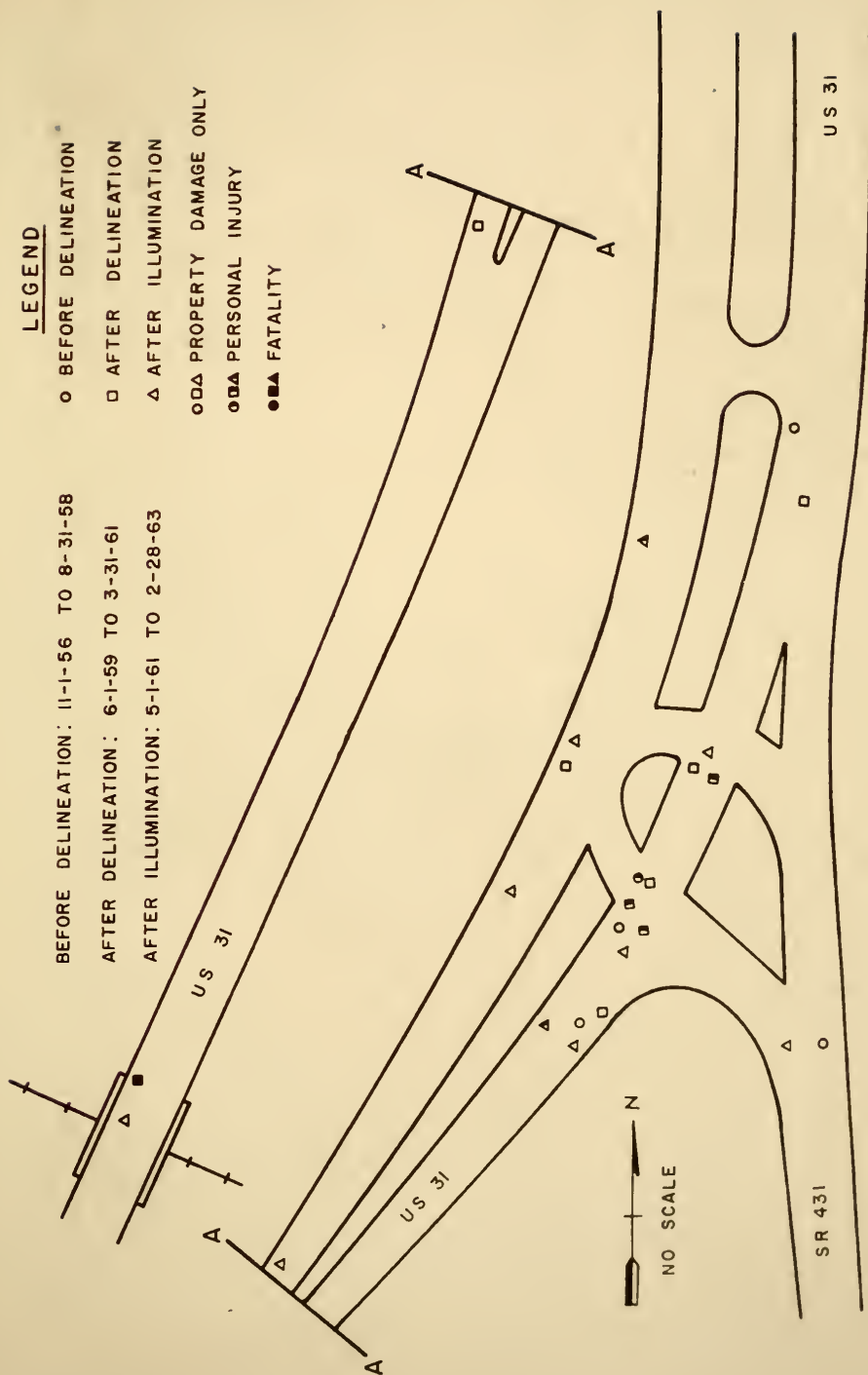


FIGURE 18 - ACCIDENT RECORD AT LOCATION II - DAYTIME

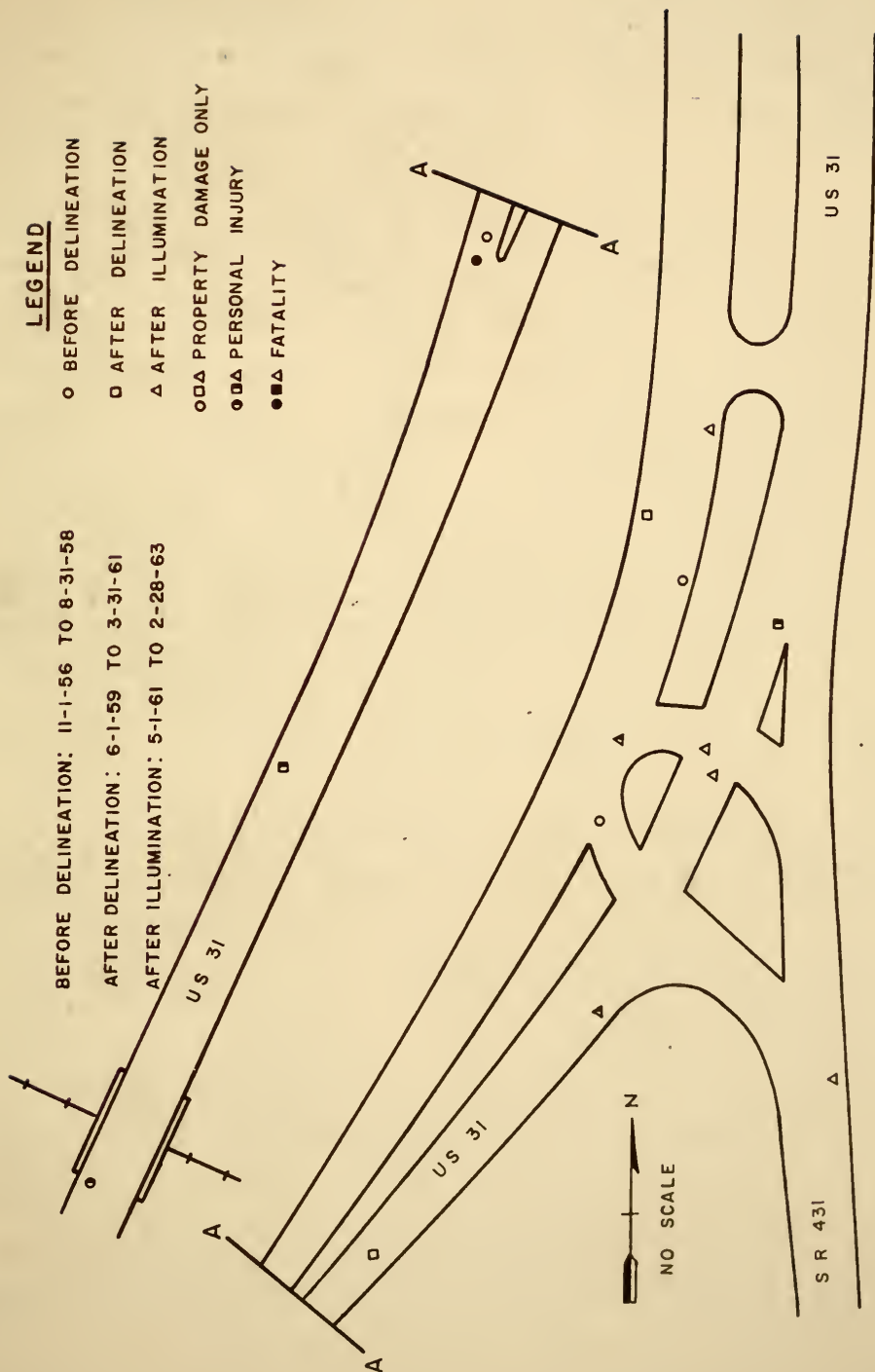


FIGURE 19 - ACCIDENT RECORD AT LOCATION II - NIGHTTIME



The daytime accident costs at Location II were 6000, 36,600, and 5600 dollars for the before, after-delineation and after-illumination periods, respectively. The values for the nighttime periods were 37,300, 5400, and 4400 dollars.

Considering other factors as constants, illumination has been more beneficial in reducing accidents at Location I. Delineation had its greatest effect on nighttime accident reduction at Location II. At Location I delineation brought a small decrease in accident rates, but accident severities and costs increased. Illumination at Location I caused large decreases in accident rates, severity, and cost. At Location II nighttime accident severities, rates, and costs dropped from the before to after-delineation period. During the after-illumination period accident rates were intermediate between the before and after-delineation rates, but costs were lowest due to decreased accident severities.

Quality Index of Traffic Flow

A summary of the quality indices for each study condition is presented in Table 7. These indices include both directions of travel and, at Location I, both passenger cars and trucks.

An examination of Table 7 shows different patterns for the quality indices at the two locations. At Location I the traffic-flow-quality index increased from the daytime-before to daytime-after condition. At Location II this index was higher for the daytime-before than the daytime-after condition.

Nighttime indices at Location I increased from one condition to the next. The nighttime-after-delineation index was higher than that for the

TABLE 7
QUALITY INDICES

Condition	Location I	Location II
Day-Before	1.39	5.52
Day-After	1.85	3.78
Night-Before	1.34	3.29
Night-After-Delineation	1.46	4.32
Night-After-Illumination	1.65	3.28

nighttime-before. A larger index was calculated for the nighttime-after illumination as compared to the nighttime-after delineation. However, at Location II this pattern was not evident. The quality index was largest for the night-after-delineation period. The before and the after-illumination indices were approximately equal.

Traffic-flow quality indices were larger at Location II than at Location I (in the ratio of about two or three to one). Location II is of more modern design than Location I, and vehicles maintained a higher average speed with considerably less speed changes through the study section. Thus, the higher quality indices of traffic flow were indicative of more favorable travel conditions.

Speed Variations at Control Stations

Station a at each intersection was far removed from the intersection and was operated as a control station to determine the daily variation in vehicle speeds due to changes in traffic-stream characteristics. This control was not considered in the delineation study by Powers. Therefore, it was not possible to compare the daily variations in speeds for the before, after-delineation, and after-illumination conditions.

A summary of the speed variations at the control stations is presented in Table 8. Passenger-car speeds at Location I were less variable at the control station at night than during the day. In addition passenger cars approaching the intersection showed less variability in speed than did those leaving the intersection. Truck speeds at Location I followed a similar pattern of decreased variation at night. During the daytime trucks approaching the intersection had less variation in speed than did trucks leaving



TABLE 8

SPEED VARIATION AT CONTROL STATIONS

Station	Daytime Mean Speeds ($\bar{X}$)	Difference $\bar{X} - \bar{Y}$	Nighttime Mean Speeds ($\bar{Y}$)	Difference $\bar{Y} - \bar{X}$
Location I: Northbound Cars				
b	61.8	+0.2	58.5	-0.5
c	61.3	-0.3	58.3	-0.7
d	61.8	+0.2	59.2	+0.2
e	60.1	-1.5	58.9	-0.1
f	61.4	-0.2	59.6	+0.6
g	61.4	-0.2	59.4	+0.4
i	62.5	+0.9	58.9	-0.1
j	62.6	+1.0	59.0	0.0
	$\bar{X} = 61.6$ $S_{\bar{X}} = 0.78$		$\bar{Y} = 59.0$ $S_{\bar{Y}} = 0.43$	
Location I: Southbound Cars				
b	58.6	-0.2	56.7	0.0
c	59.5	+0.7	55.9	-0.8
d	60.7	+1.9	56.7	0.0
e	59.0	+0.2	56.7	0.0
f	57.5	-1.3	56.4	-0.3
g	57.5	-1.3	57.1	+0.4
h	57.6	-1.2	56.0	-0.7
i	60.5	+1.7	57.2	+0.5
j	58.5	-0.3	57.4	+0.7
	$\bar{X} = 58.8$ $S_{\bar{X}} = 1.22$		$\bar{Y} = 56.7$ $S_{\bar{Y}} = 0.51$	
Location I: Northbound Trucks				
b	53.8	-0.1	52.2	-0.8
c	52.6	-1.3	53.9	+0.9
d	53.0	-0.9	52.4	-0.6
e	52.0	-1.9	53.4	+0.4
f	54.4	+0.5	55.2	+2.2
g	55.7	+1.8	52.7	-0.3
i	54.9	+1.0	52.4	-0.6
j	54.9	+1.0	51.7	-1.3
	$\bar{X} = 53.9$ $S_{\bar{X}} = 1.29$		$\bar{Y} = 53.0$ $S_{\bar{Y}} = 1.13$	



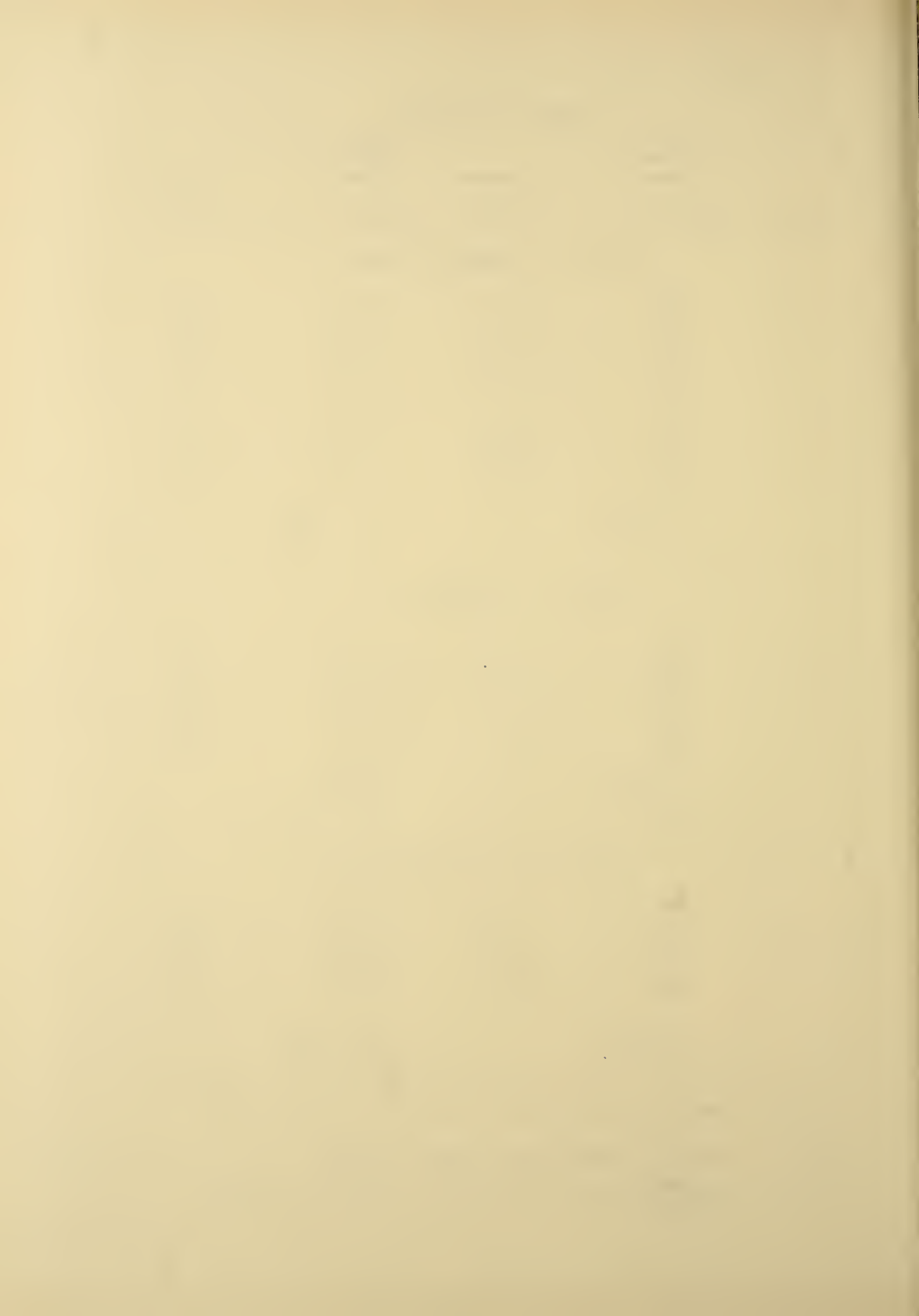
TABLE 8 (continued)

Station	Daytime Mean Speeds ($\bar{X}$)	Difference $\bar{X}-\bar{X}$	Nighttime Mean Speeds ($\bar{Y}$)	Difference $\bar{Y}-\bar{Y}$
Location I: Southbound Trucks				
b	46.4	-0.5	45.2	0.0
c	46.2	-0.7	46.0	+0.8
d	48.7	+1.8	45.1	-0.1
e	47.3	+0.4	47.0	+1.8
f	45.3	-1.6	44.9	-0.3
g	45.3	-1.6	44.7	-0.5
h	45.3	-1.6	43.7	-1.5
i	48.9	+2.0	45.3	+0.1
j	48.9	+2.0	44.7	-0.5
	$\bar{X} = 46.9$ $S_{\bar{X}} = 1.57$		$\bar{Y} = 45.2$ $S_{\bar{Y}} = 0.92$	
Location II: Northbound Cars				
b	55.3	-0.1	53.1	-0.6
f	55.5	+0.1	53.8	+0.1
g	55.1	-0.3	53.6	-0.1
h	55.8	+0.4	52.6	-1.1
i	54.7	-0.7	53.5	-0.2
j	55.9	+0.5	55.5	+1.8
	$\bar{X} = 55.4$ $S_{\bar{X}} = 0.45$		$\bar{Y} = 53.7$ $S_{\bar{Y}} = 0.98$	
Location II: Southbound Cars				
b	55.2	-0.8	52.7	-1.5
c	55.0	-1.0	54.6	+0.4
d	55.5	-0.5	53.9	-0.3
e	57.6	+1.6	54.2	0.0
j	56.9	+0.9	55.6	+1.4
	$\bar{X} = 56.0$ $S_{\bar{X}} = 1.15$		$\bar{Y} = 54.2$ $S_{\bar{Y}} = 1.06$	

Station: Denotes station operated simultaneously with control station a.

$\bar{X}$, $\bar{Y}$: Individual mean speed at control station

$\bar{X}$, $\bar{Y}$: Overall average speed at control station for given condition



the intersection. The reverse was true at night. The magnitude of the day-to-day speed variations for trucks was higher than for cars. Little pattern was noted in the speed variations at the control station for Location II. Vehicles approaching the intersection had larger daily variations in speed for nighttime than for daytime operation. The reverse pattern was evident for vehicles leaving the intersection. For daytime operation vehicles approaching the intersection had less speed variation than vehicles leaving the intersection. Nighttime speed variations were nearly equal for the two directions of travel.

The standard deviations of the mean speeds at the control stations were generally less than 1.00 mph for nighttime travel conditions. This standard deviation was less than the variability allowed for in the design of the experiment. However, during daytime operation these standard deviations were generally slightly more than 1.00.

Benefit-Cost Analysis

It is becoming increasingly necessary to perform economic analyses to justify expenditures for proposed improvements or to indicate the comparative worth of proposed alternates. The road-user, benefit-cost ratio is one method of economic analysis that is frequently used in the evaluation of highway improvements.

A summary of nighttime costs for each condition at both locations is given in Table 9. Table 10 presents benefit-cost ratios where each pair of conditions have been compared.

An examination of Table 10 indicated that the addition of delineation at Location I resulted in a large negative benefit-cost ratio (road-user



TABLE 9

SUMMARY OF NIGHTTIME ROAD USER AND HIGHWAY COSTS
(dollars per million vehicle miles)

Condition	Time Costs	Operating Costs	Accident Costs	Delineation Costs	Illumination Costs	Total Road User Costs	Total Highway Costs
Location I							
Before	45,980	89,572	7,303	-	-	142,885	-
After Delineation	45,540	90,526	14,321	310	-	150,380	310
After Illumination	44,235	92,503	886	-	1,572	137,624	1,572
Location II							
Before	32,612	58,703	32,568	-	-	123,883	-
After Delineation	31,365	61,003	3,974	412	-	96,342	412
After Illumination	31,494	60,431	2,801	-	3,732	94,726	3,732

TABLE 10
BENEFIT-COST RATIOS

Conditions Compared	Location I	Location II
Nighttime-Before to Nighttime-After-Delineation	-24.27	66.85
Nighttime-Before to Nighttime-After-Illumination	3.33	7.81
Nighttime-After-Delineation to Nighttime-After-Illumination	8.12	0.43



costs increased after the additional expenditure for delineation). Benefit-cost ratios greater than 1.00 were calculated for the night-after-illumination condition when compared with either the night-before or the night-after-delineation condition. The illumination showed a benefit-cost ratio of 3.33 when compared with the night-before condition, and an 8.12 ratio when compared to the night-after-delineation condition. Considering that a benefit-cost ratio of 1.00 represents the point where road-user savings just balance the costs of the improvement, the illumination at Location I was justified from an economic standpoint.

At Location II a very high benefit-cost ratio of 66.85 was calculated for the night-before, night-after-delineation comparison. Illumination also provided an improvement over the before condition with a benefit-cost ratio of 7.81. However, a benefit-cost ratio of only 0.43 was noted when the night-after-illumination condition was compared with the night-after-delineation condition. At Location II it appears that both delineation and illumination offer improvements over the before condition. The delineation treatment is preferable to the illumination from an economic standpoint because the additional cost of illumination above that for delineation is not offset by savings in road-user costs. However, the illumination may be justified from the standpoint of comfort, convenience, and ease of travel through the lighted intersection.

Proposed Criterion for Nighttime

Visibility Improvements

Although this study was limited to two intersections, a general investigation was conducted to determine the effect of nighttime traffic volumes

on benefit-cost ratios and on traffic-flow quality indices. The nighttime traffic volumes were obtained from the Planning Division of the Indiana State Highway Commission, and were the volumes of traffic passing through the intersection during the hours of darkness for the average night. The percent increase in traffic-flow quality indices from one period to the next was plotted against the average annual nighttime volume (Figure 20). The benefit-cost ratios for each comparison were plotted against the average annual nighttime volume, as shown in Figure 21.

An investigation of Figure 20 indicated that for low nighttime volumes the greater increase in the quality index over the night-before condition occurred during the night-after-delineation period. However, at high nighttime volumes the greater increase was noted during the night-after-illumination period. The nighttime volume at which the percent increase in the quality index over the night-before condition was equal for both delineation and illumination was approximately 2700 vehicles per night.

Figure 21 revealed a similar pattern for the benefit-cost ratios. At low nighttime volumes the larger benefit-cost ratio over the night-before condition was evident during the night-after-delineation period. At high nighttime volumes the greater benefit-cost ratio occurred during the night-after-illumination condition. The nighttime volume at which the benefit-cost ratios for both delineation and illumination, when compared with the before condition, were equal was approximately 2600 vehicles per night.

At low nighttime volumes delineation was rated higher than illumination while at high nighttime volumes illumination was rated higher. The division point between the addition of delineation and that of illumination was approximately 2600 to 2700 vehicles per night. No general conclusions could be drawn because the above data represented only two intersections.

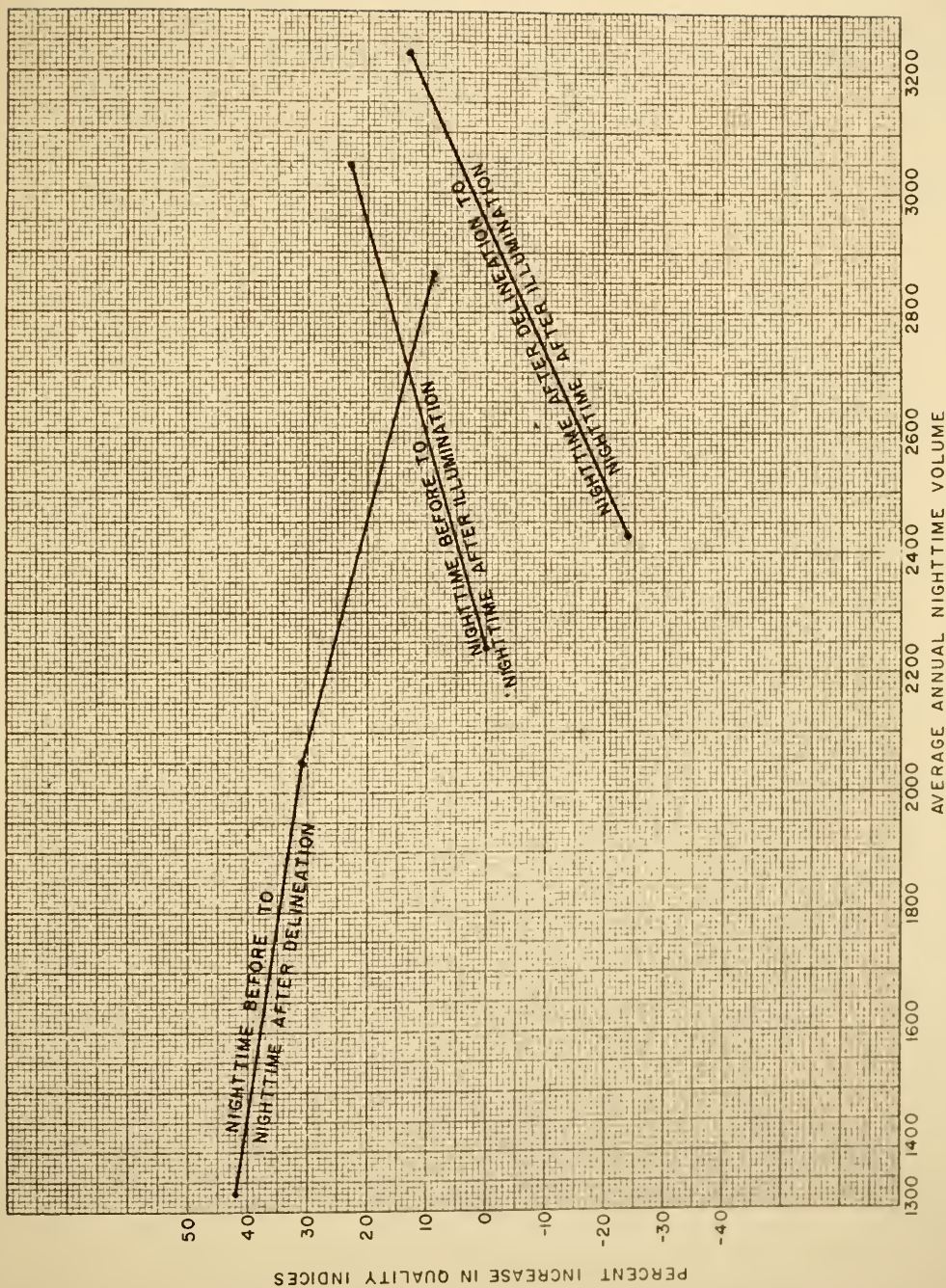


FIGURE 20 - THE EFFECT OF NIGHTTIME VOLUME ON QUALITY INDICES

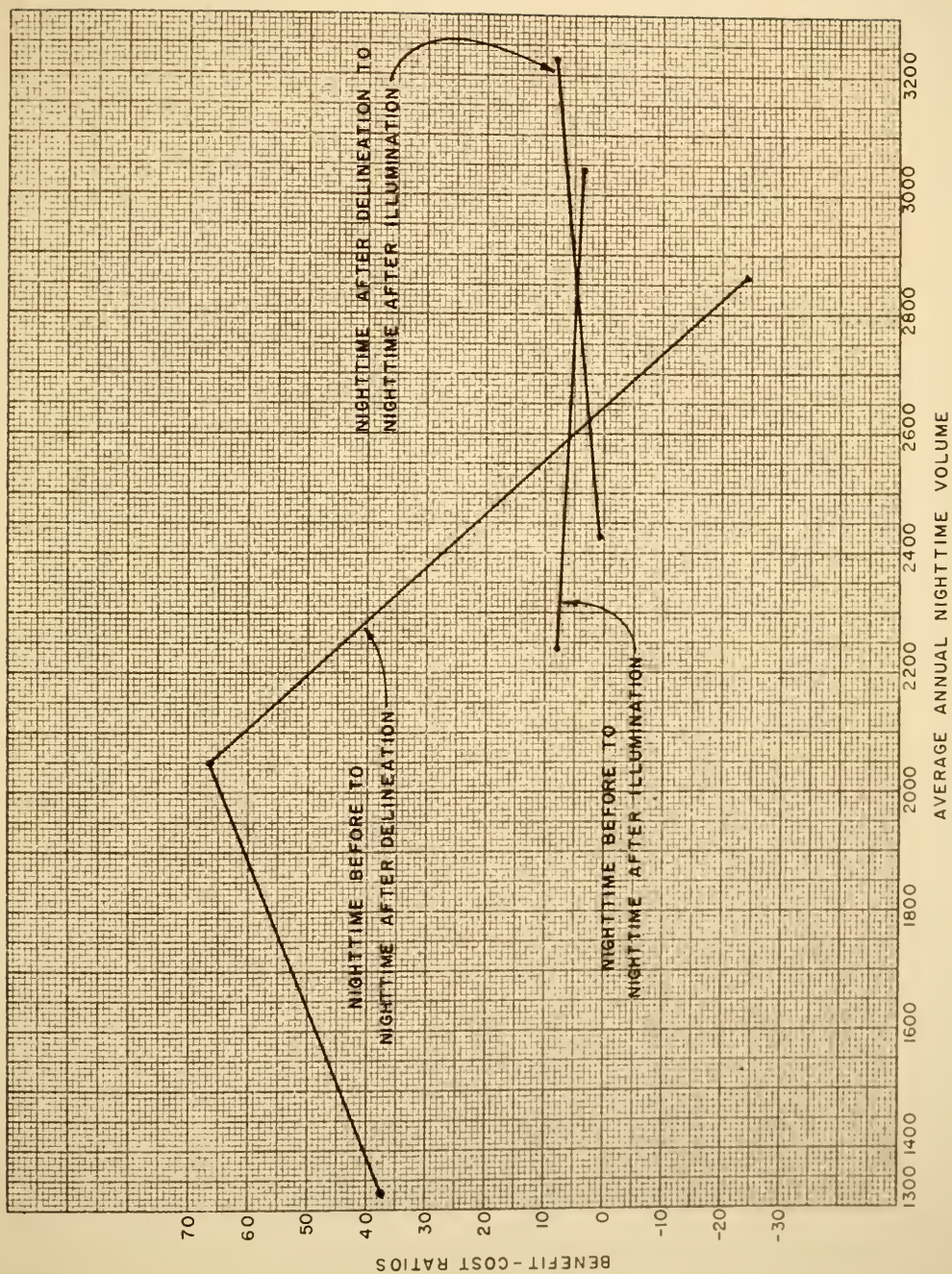


FIGURE 21 - THE EFFECT OF NIGHTTIME VOLUME ON BENEFIT-COST RATIOS

TABLE 11

SUMMARY OF NIGHTTIME RESULTS

	Location I			Location II		
	Before	After-Delineation	After-Illumination	Before	After-Delineation	After-Illumination
Average Speed	44.9	45.5	47.0	49.6	52.4	51.8
Quality Index	1.34	1.46	1.65	3.29	4.32	3.28
Accident Rates	3.97	2.72	1.04	5.05	3.41	4.42
Accident Costs	\$14,300	\$31,800	\$2,200	\$37,300	\$5,400	\$4,400
Benefit-Cost Ratios		-24.27 ^a	3.33 ^a		66.85 ^a	7.81 ^a
			8.12 ^b			0.43 ^b

^a : Basic condition was the before period^b : Basic condition was the after-delineation period

SUMMARY OF RESULTS AND RECOMMENDATIONS

The conclusions inferred from the results of this investigation are valid only for the conditions found at the two study intersections. However, the real benefits of research are realized through generalizations deduced for an entire population. The following conclusions concerning the traffic-stream characteristics of rural intersections were drawn from the findings of this research investigation.

1. Daytime speeds for both cars and trucks were generally higher for the after condition than for the before condition. Daytime passenger-car and truck speeds increased at an annual rate of 0.4 and 0.8 mph per year, respectively. This is less than the reported national average increase of approximately 0.5 mph per year.
2. Nighttime passenger-car speeds tended to be slightly higher for the after-delineation period than for the before period. There were few changes in truck speeds for the same conditions. Therefore nighttime speeds were assumed to be constant with time when intersections are not illuminated.
3. Both passenger-car and truck speeds were higher in the night-after-illumination period than in the night-before period.
4. Speeds at Location I were generally higher in the night-after-illumination period than in the night-after-delineation period. At Location II after-illumination speeds were slightly lower than after-delineation speeds.

5. Vehicle speeds generally increased more during the night-after-illumination period than during the night-after-delineation period.
6. The variances of vehicle speeds at the control stations were generally less than that allowed for in the design of the experiment. Thus, no significant day-to-day variation in vehicular speeds was detected in this research investigation. Truck speeds were more variable than passenger car speeds and nighttime speeds were generally more consistent than daytime speeds.
7. The variance of vehicle speeds was little affected by the addition of delineation or illumination.
8. Nighttime traffic-flow quality indices were highest at Location I during the after-illumination period than for the other periods. The poorest quality of flow was calculated for the before period. At Location II the highest quality of flow was evidenced during the after-delineation period. The quality indices were nearly equal for the night-before and night-after-illumination periods.
9. Nighttime accident costs at both locations were lowest for the after-illumination condition. Numbers of accidents and accident rates were also lowest for the illuminated period at Location I. However, at Location II the lowest numbers of accidents and the lowest accident rates were evidenced during the after-delineation period.
10. From an economic standpoint illumination was more justified than delineation at Location I. The benefit-cost ratios indicated that it would be better to leave the intersection in the before condition than to add only delineation. At Location II the

delineation was more beneficial than the illumination because the extra cost of providing the illumination was not entirely offset by savings to road users.

11. The delineation was rated higher than illumination when nighttime volumes were below 2600 to 2700 vehicles per night. At larger nighttime volumes illumination proved to be more beneficial than delineation.

Illumination was apparently more desirable at Location I. There was less evidence in support of the illumination at Location II. However, Location II was more modern in design than Location I, and nighttime volumes at Location II were about one-third less than nighttime volumes at Location I.

The nighttime volume apparently affected the amount of improvement in operational characteristics which could be attributed to improved nighttime visibility. An additional investigation should be undertaken to determine the correlation between nighttime volumes and the beneficial effects of delineation and illumination. If the two are highly correlated, nighttime-volume warrants could be developed for the proper selection of nighttime visibility improvements.

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APPENDIX A

APPENDIX A

TABLE 12

SUMMARY OF PROCESSED DATA

Station	Condition	n	$\bar{X}$	s	P ₈₅	Pace	Percent in Pace
Location I: Northbound Cars							
a	DB	146	57.8	6.7	64.5	54.5	59.00
	DA	140	61.77	5.43	66.49	55.0	66.43
	NB	98	56.5	6.9	62.3	52.0	58.00
	NAD	190	57.9	7.1	65.2	52.5	53.00
	NAI	140	58.47	6.65	64.99	52.0	57.14
b	DB	180	51.3	5.7	57.5	45.0	56.00
	DA	145	55.75	6.58	62.37	49.0	53.79
	NB	135	49.2	5.9	54.5	44.5	64.5
	NAD	116	50.4	6.0	55.8	45.5	63.00
	NAI	142	54.11	6.11	59.74	48.0	59.15
c	DB	369	45.7	5.3	51.0	42.0	71.00
	DA	140	45.66	4.79	49.93	40.0	72.85
	NB	135	44.0	5.3	49.6	40.0	64.00
	NAD	128	42.4	6.3	48.5	38.0	57.00
	NAI	140	45.74	5.90	50.79	39.0	66.43
d	DB	165	43.2	5.7	49.4	39.0	60.00
	DA	140	42.49	4.91	46.99	37.0	70.00
	NB	144	40.0	6.2	47.5	31.5	48.00
	NAD	71	41.1	6.4	48.3	35.0	53.00
	NAI	140	41.36	4.99	46.16	36.0	72.85
e	DB	133	35.8	6.3	42.6	30.0	57.00
	DA	141	39.71	4.55	43.97	32.0	70.92
	NB	127	34.8	5.2	39.5	29.0	70.00
	NAD	111	34.3	4.4	39.4	28.5	77.00
	NAI	140	39.09	5.11	44.24	32.0	65.71
f	DB	138	50.2	5.2	55.2	46.0	72.00
	DA	142	52.21	5.93	57.67	46.0	64.08
	NB	378	46.4	7.0	53.8	41.0	52.00
	NAD	257	48.0	5.5	53.5	43.0	68.00
	NAI	141	48.89	5.46	54.40	43.0	58.15
g	DB	118	57.8	6.4	63.5	53.0	67.00
	DA	140	57.97	6.18	67.66	52.0	57.86
	NB	112	51.9	7.2	59.7	44.0	51.00
	NAD	162	55.2	7.2	62.5	48.5	56.00
	NAI	140	54.36	6.94	60.99	48.0	55.71

Continued Next Page

TABLE 12 (continued)

Station	Condition	n	$\bar{X}$	s	P ₈₅	Pace		Percent in Pace
i	DB	237	57.3	7.6	65.5	55.0	65.0	44.00
	DA	141	59.19	7.65	66.46	54.0	64.0	51.77
	NB	140	52.3	7.2	59.0	49.0	59.0	51.00
	NAD	140	56.1	8.5	64.0	53.0	63.0	49.00
	NAI	140	55.62	6.89	66.79	50.0	60.0	53.57
j	DB	168	57.8	7.2	64.5	51.0	65.0	48.00
	DA	140	59.32	6.78	65.59	52.0	62.0	55.71
	NB	143	55.2	8.0	63.5	51.0	62.0	50.00
	NAD	136	55.7	8.1	63.8	52.5	62.5	48.5
	NAI	140	56.81	7.28	63.57	52.0	62.0	47.86
Location I: Southbound Cars								
a	DB	129	55.2	6.4	61.1	51.0	61.0	60.00
	DA	140	55.62	6.28	61.59	49.0	59.0	59.28
	NB	115	53.1	6.7	60.2	45.0	56.0	53.00
	NAD	251	55.2	7.1	62.5	49.0	59.0	56.00
	NAI	141	56.74	6.89	61.98	50.0	60.0	59.57
b	DB	206	48.8	5.8	54.3	44.0	55.0	60.00
	DA	144	53.34	5.68	58.17	48.0	58.0	64.58
	NB	142	45.5	5.6	51.5	41.0	51.0	63.00
	NAD	88	46.2	5.6	52.2	41.0	52.0	61.00
	NAI	144	52.40	5.82	58.19	46.0	56.0	64.58
c	DB	288	41.7	4.9	46.5	37.0	47.0	72.00
	DA	140	45.29	4.99	49.88	41.0	51.0	71.43
	NB	118	37.8	5.0	43.2	32.0	42.0	72.00
	NAD	143	40.7	4.7	44.5	35.5	45.5	78.5
	NAI	141	45.09	5.14	50.40	38.0	48.0	64.54
d	DB	100	40.5	5.9	46.5	35.0	47.0	58.00
	DA	140	43.80	4.90	48.66	39.0	49.0	70.71
	NB	135	40.2	4.9	45.5	35.0	45.5	70.00
	NAD	73	38.1	5.9	43.7	32.5	43.5	65.00
	NAI	139	42.10	5.11	46.71	36.0	46.0	71.94
e	DB	125	36.6	5.1	42.0	31.0	41.0	69.00
	DA	141	37.91	4.83	42.09	33.0	43.0	72.34
	NB	115	32.6	5.3	38.5	27.5	37.5	67.5
	NAD	116	33.5	4.9	38.3	27.5	38.0	70.5
	NAI	139	35.33	5.26	39.81	30.0	40.0	66.18

Continued Next Page

TABLE 12 (continued)

Station	Condition	n	$\bar{X}$	s	P_{85}	Pace		Percent in Pace
f	DB	130	51.3	5.9	57.2	46.0	56.0	64.00
	DA	140	48.72	4.90	52.59	42.0	52.0	72.14
	NB	450	46.0	6.8	52.5	40.0	50.0	57.00
	NAD	223	47.3	5.7	53.5	40.5	50.5	63.5
	NAI	142	44.79	5.47	50.23	38.0	48.0	64.08
g	DB	93	57.3	6.1	63.5	51.0	62.0	64.00
	DA	140	55.36	6.56	60.99	51.0	61.0	58.57
	NB	110	54.6	7.6	62.5	47.0	57.0	51.00
	NAD	153	55.1	8.3	64.3	49.0	60.0	45.00
	NAI	141	52.21	6.67	59.12	42.0	52.0	49.64
h	DB	192	37.1	4.6	41.5	32.0	42.0	74.00
	DA	140	33.52	4.34	37.83	27.0	37.0	74.28
	NB	120	32.2	4.4	36.5	28.0	38.0	77.00
	NAD	65	33.9	5.7	40.2	29.5	39.5	66.5
	NAI	160	33.20	4.03	37.33	27.0	37.0	76.87
i	DB	253	54.2	6.8	60.5	51.0	62.0	60.00
	DA	139	51.71	6.93	58.78	43.0	53.0	51.08
	NB	108	49.8	8.1	59.5	40.5	50.5	47.00
	NAD	186	52.8	7.0	60.0	48.0	58.5	54.00
	NAI	139	51.74	6.84	57.73	48.0	58.0	56.83
j	DB	176	53.5	7.0	60.6	47.0	57.0	55.5
	DA	141	55.84	6.67	61.96	49.0	59.0	58.15
	NB	232	50.9	7.2	57.7	47.0	57.0	56.00
	NAD	172	53.6	7.3	61.0	47.0	59.0	49.00
	NAI	131	51.68	7.21	58.11	38.0	48.0	32.83
Location I: Northbound Trucks								
a	DB	53	49.5	5.3	55.5	43.0	54.0	71.00
	DA	60	51.56	5.26	56.59	47.0	57.0	68.33
	NB	56	49.3	4.4	53.7	44.5	54.5	80.00
	NAD	71	48.5	3.8	52.2	43.5	53.5	82.5
	NAI	60	52.22	3.88	55.49	47.0	57.0	84.99
b	DB	23	46.1	2.8	49.3	41.5	51.5	96.00
	DA	60	48.82	5.18	52.66	43.0	53.0	73.33
	NB	52	43.9	4.6	47.2	38.0	48.0	79.5
	NAD	93	45.1	4.3	49.7	41.0	51.0	76.00
	NAI	59	49.79	4.68	54.02	45.0	55.0	72.88

Continued Next Page

TABLE 12 (continued)

Station	Condition	n	$\bar{X}$	s	P ₈₅	Pace	Percent in Pace	
c	DB	63	40.5	5.3	46.0	36.0	46.0	68.5
	DA	60	46.09	6.07	52.99	37.0	47.0	56.66
	NB	33	43.2	3.5	47.0	37.0	47.0	85.5
	NAD	95	42.9	4.9	47.8	38.0	48.5	68.00
	NAI	60	46.57	5.03	51.99	40.0	50.0	64.99
d	DB	38	43.7	5.1	48.8	39.0	49.0	63.5
	DA	60	42.42	4.50	46.49	38.0	48.0	79.99
	NB	114	41.2	5.2	46.8	38.0	48.5	74.00
	NAD	59	41.8	4.6	46.3	37.0	47.0	76.5
	NAI	61	43.07	5.41	47.80	35.0	45.0	57.37
e	DB	20	37.9	3.1	40.3	31.5	42.0	89.5
	DA	60	41.11	5.30	46.66	32.0	42.0	53.33
	NB	43	38.5	3.5	41.7	32.5	43.0	86.00
	NAD	70	37.5	5.0	42.2	33.0	43.0	71.5
	NAI	60	41.92	5.02	45.74	35.0	45.0	71.66
f	DB	41	37.5	5.0	43.0	32.0	44.0	62.00
	DA	60	47.12	6.48	48.99	31.0	41.0	35.00
	NB	78	41.8	5.8	47.8	38.0	48.0	62.00
	NAD	105	39.5	5.8	45.2	36.0	46.0	64.00
	NAI	60	42.92	5.79	48.66	37.0	47.0	63.33
g	DB	32	45.7	4.9	50.8	40.0	51.0	71.00
	DA	60	46.64	5.03	51.49	40.0	50.0	74.99
	NB	65	48.1	4.9	53.0	42.5	53.5	73.00
	NAD	138	47.3	3.8	51.0	42.5	52.5	85.00
	NAI	60	47.46	4.55	51.74	42.0	52.0	69.99
i	DB	36	46.6	4.8	51.2	43.5	53.5	79.00
	DA	60	48.46	5.21	53.33	46.0	56.0	64.99
	NB	54	46.0	3.9	50.5	41.5	41.5	80.00
	NAD	47	44.2	5.3	49.3	39.0	49.0	70.5
	NAI	60	48.77	5.67	53.33	41.0	51.0	64.89
j	DB	33	48.9	4.1	53.3	43.0	54.0	76.00
	DA	60	50.24	5.81	55.49	44.0	54.0	64.99
	NB	29	46.0	4.5	51.3	42.0	52.0	75.00
	NAD	40	46.9	4.7	50.2	42.0	52.0	81.00
	NAI	60	55.79	5.19	56.99	46.0	56.0	69.99

Continued Next Page

TABLE 12 (continued)

Station	Condition	n	$\bar{X}$	s	P ₈₅	Pace	Percent in Pace	
Location I: Southbound Trucks								
a	DB	57	45.3	3.6	49.3	40.0	51.0	79.00
	DA	60	46.36	4.20	49.83	40.0	50.0	76.66
	NB	75	43.5	4.4	47.5	38.5	48.5	80.5
	NAD	102	41.9	4.3	46.0	35.0	45.0	76.5
	NAI	60	45.19	3.88	49.24	39.0	49.0	79.99
b	DB	46	41.4	4.4	45.8	36.5	47.0	78.00
	DA	62	46.81	3.40	49.81	43.0	53.0	91.93
	NB	88	38.5	4.2	42.8	33.5	45.0	75.5
	NAD	134	37.9	4.2	42.0	33.0	43.0	78.00
	NAI	63	43.15	3.85	46.30	37.0	47.0	87.29
c	DB	66	36.9	4.3	41.5	33.0	43.0	79.00
	DA	60	43.06	3.94	47.14	36.0	46.0	74.99
	NB	71	36.1	4.9	41.5	32.0	42.5	68.00
	NAD	147	37.9	4.3	42.4	32.5	43.0	75.00
	NAI	60	43.29	4.66	47.66	36.0	46.0	71.66
d	DB	56	38.2	4.4	42.5	34.0	44.0	73.5
	DA	60	41.67	4.48	45.99	37.0	47.0	74.99
	NB	97	38.4	4.8	42.4	33.5	43.5	78.00
	NAD	80	37.9	4.5	41.7	32.0	42.5	76.5
	NAI	60	39.93	4.31	43.85	35.0	45.0	81.66
e	DB	45	37.6	4.5	42.5	33.0	43.0	74.00
	DA	59	40.33	4.68	45.57	34.0	44.0	69.49
	NB	67	36.3	4.7	41.3	30.0	41.0	71.00
	NAD	97	37.4	4.5	42.3	32.5	43.0	73.00
	NAI	60	36.33	4.67	39.99	30.0	40.0	74.99
f	DB	53	42.6	4.9	48.0	38.0	49.0	69.00
	DA	60	44.61	4.11	48.49	39.0	49.0	76.66
	NB	148	42.7	5.3	48.5	38.5	48.5	67.00
	NAD	175	42.1	4.5	46.3	37.0	47.5	74.00
	NAI	60	41.24	4.28	44.99	36.0	46.0	78.33
g	DB	46	47.3	5.0	52.0	43.0	53.0	71.5
	DA	60	42.61	4.54	46.99	38.0	48.0	74.99
	NB	73	48.1	4.0	52.6	43.0	53.0	90.00
	NAD	190	48.5	4.6	53.1	42.5	53.0	74.00
	NAI	60	46.82	3.86	50.99	40.0	50.0	79.99

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TABLE 12 (continued)

Station	Condition	n	$\bar{X}$	s	P ₈₅	Pace	Percent in Pace	
h	DB	47	37.2	5.1	42.5	32.0	43.0	64.00
	DA	61	35.27	4.87	39.96	30.0	40.0	70.49
	NB	78	34.6	5.3	40.0	29.5	40.5	66.00
	NAD	50	37.5	3.9	41.4	33.5	43.5	81.00
	NAI	60	34.21	3.96	38.33	29.0	39.0	79.99
i	DB	64	44.3	4.5	48.2	39.5	49.5	78.5
	DA	60	42.66	4.58	47.66	36.0	46.0	71.66
	NB	80	42.2	4.1	46.5	36.5	47.5	77.00
	NAD	66	40.1	4.8	44.8	35.0	45.0	77.00
	NAI	60	42.41	5.02	46.49	36.0	46.0	74.99
j	DB	57	46.5	4.7	51.0	42.0	52.0	76.00
	DA	60	46.22	3.59	49.19	40.0	50.0	84.99
	NB	91	44.3	3.8	48.5	39.5	49.5	84.00
	NAD	66	42.4	4.2	46.2	37.0	48.0	82.5
	NAI	60	44.71	4.39	48.74	40.0	50.0	74.99
Location II: Northbound Cars								
a	DB	177	54.1	8.2	62.5	49.0	59.0	52.00
	DA	140	55.33	6.03	60.99	50.0	60.0	62.14
	NB	116	53.5	9.1	61.5	48.0	59.0	49.00
	NAD	197	54.6	7.6	62.5	50.0	60.0	48.5
	NAI	140	53.13	7.24	60.24	45.0	55.0	50.71
b	DB	187	50.5	7.5	58.0	44.0	56.0	50.00
	DA	141	48.84	5.89	54.40	45.0	55.0	63.83
	NB	124	47.8	6.7	54.6	44.0	55.0	52.00
	NAD	157	51.9	7.1	59.0	46.0	57.0	55.00
	NAI	142	47.40	7.29	54.73	40.0	50.0	52.11
f	DB	161	55.2	6.7	61.5	49.0	59.0	59.00
	DA	142	60.73	6.26	66.78	54.0	64.0	59.86
	NB	119	56.9	7.8	63.0	52.0	63.0	56.00
	NAD	295	55.9	8.6	65.0	51.0	62.0	43.00
	NAI	140	58.58	7.65	66.24	54.0	64.0	47.68
g	DB	125	54.8	7.1	61.8	49.0	59.0	54.00
	DA	148	59.46	7.68	66.29	54.0	64.0	52.03
	NB	132	52.9	7.6	59.6	49.0	59.0	56.00
	NAD	320	51.1	7.8	59.0	45.0	56.0	50.00
	NAI	140	53.41	8.16	60.79	50.0	60.0	47.86

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TABLE 12 (continued)

Station	Condition	n	$\bar{X}$	s	P ₈₅	Pace	Percent in Pace	
h	DB	188	49.4	7.1	56.8	47.0	57.0	50.00
	DA	142	49.99	7.04	56.53	43.0	53.0	53.52
	NB	103	45.6	6.8	52.5	42.0	52.0	55.00
	NAD	198	48.9	7.7	56.5	45.0	56.0	53.00
	NAI	140	45.84	6.33	50.83	41.0	51.0	61.43
i	DB	161	42.9	6.7	49.8	48.5	58.5	55.00
	DA	140	40.48	7.06	46.79	36.0	46.0	52.86
	NB	109	38.5	6.6	44.2	34.5	44.5	64.00
	NAD	246	41.0	7.6	49.5	36.0	47.0	50.00
	NAI	140	40.71	6.75	47.74	32.0	42.0	55.71
j	DB	77	44.2	8.3	51.8	38.0	48.0	50.00
	DA	140	40.26	6.24	46.49	35.0	45.0	56.43
	NB	74	39.7	5.9	46.5	32.5	42.5	57.00
	NAD	197	40.4	7.4	47.0	34.0	44.0	55.00
	NAI	140	38.10	5.43	42.74	31.0	41.0	68.57
Location II: Southbound Cars								
a	DB	153	54.7	8.0	62.5	50.0	60.0	50.00
	DA	139	55.17	5.98	60.99	50.0	60.0	62.14
	NB	126	51.6	8.2	59.0	48.0	58.0	53.00
	NAD	181	54.3	8.3	61.5	51.0	62.0	50.00
	NAI	140	52.70	6.37	58.99	46.0	56.0	51.43
b	DB	164	52.8	7.0	60.1	50.0	62.0	52.00
	DA	144	52.03	7.24	59.34	46.0	56.0	50.69
	NB	139	48.1	8.9	56.7	46.0	56.0	47.5
	NAD	159	52.4	8.9	62.3	46.0	57.0	41.00
	NAI	140	48.84	7.24	55.74	46.0	56.0	52.86
c	DB	196	50.9	6.5	56.8	47.0	57.0	60.00
	DA	140	52.71	6.37	58.99	46.0	56.0	59.28
	NB	113	46.3	8.0	54.0	43.0	55.0	44.00
	NAD	219	49.3	7.6	57.5	44.0	56.0	48.00
	NAI	140	49.58	6.90	56.66	46.0	56.0	46.43
d	DB	283	54.8	7.8	62.5	49.0	59.0	54.00
	DA	156	58.10	7.19	65.39	53.0	63.0	55.77
	NB	207	53.4	8.6	62.5	44.0	54.0	43.00
	NAD	359	52.3	8.3	61.0	48.0	59.0	45.00
	NAI	140	57.19	6.92	63.99	53.0	63.0	56.43

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TABLE 12 (continued)

Station	Condition	n	$\bar{X}$	s	P ₈₅	Pace	Percent in Pace	
e	DB	154	56.1	8.7	65.2	50.0	62.0	44.00
	DA	140	61.87	6.04	68.49	56.0	66.0	55.71
	NB	201	53.5	9.0	61.5	51.0	61.0	51.00
	NAD	244	55.9	8.5	64.5	50.0	61.0	45.00
	NAI	140	58.14	7.46	64.74	55.0	65.0	52.14
f	DB	79	38.9	6.3	44.5	34.0	44.0	61.00
	DA	140	36.72	4.88	41.16	29.0	39.0	72.85
	NB	81	37.2	6.6	44.5	30.0	40.0	63.00
	NAD	202	37.0	5.4	43.0	30.0	40.0	67.00
	NAT	140	36.46	4.97	41.66	29.0	39.0	69.28

DB = Day-before

DA = Day-after

NB = Night-before

NAD = Night-after-delineation

NAI = Night-after-illumination

n = number of observations in sample

 $\bar{X}$ = sample mean, mph

s = sample standard deviation, mph

P₈₅ = sample 85th-percentile speed, mph

TABLE 13
TESTS ON DIFFERENCES BETWEEN DAYTIME MEANS

Two-sided test; $\alpha = 0.05$					
Station	Mean Speeds by Condition (mph)		Test		Result
	DB	DA	t_o	t_c	
Location I: Northbound Cars					
a	57.8	61.8	5.49	1.97	H
b	51.3	55.8	6.57	1.97	H
c	45.7	45.7	-0.08	-1.97	-
d	43.2	42.5	-1.15	-1.97	-
e	35.8	39.7	5.91	1.97	H
f	50.2	52.2	3.01	1.97	H
g	57.8	58.0	0.22	1.97	-
i	57.3	59.2	2.33	1.97	H
j	57.8	59.3	1.89	1.97	-
Location I: Southbound Cars					
a	55.2	55.6	0.54	1.97	-
b	48.8	53.3	7.67	1.97	H
c	41.7	45.3	4.33	1.97	H
d	40.5	43.8	4.76	1.97	H
e	36.6	37.9	2.15	1.97	H
f	51.3	48.7	-3.92	-1.97	L
g	57.3	55.4	-2.27	-1.97	L
h	37.1	33.5	-7.17	-1.97	L
i	54.2	51.7	-3.44	-1.97	L
j	53.5	55.8	3.02	1.97	H
Location I: Northbound Trucks					
a	49.5	51.6	2.07	1.98	H
b	46.1	48.8	2.38	1.99	H
c	40.5	46.1	5.45	1.97	H
d	43.7	42.4	-1.30	-1.98	-
e	37.9	41.1	2.56	2.00	H
f	37.5	47.1	8.01	1.99	H
g	45.7	46.6	0.86	1.99	-
i	46.6	48.5	1.75	1.99	-
j	48.9	50.2	1.17	1.99	-

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TABLE 13 (continued)

Station	Mean Speeds by Condition (mph)		Test		Result
	DB	DA	t_o	t_c	
Location I: Southbound Trucks					
a	45.3	46.4	1.46	1.98	-
b	41.4	46.8	7.61	1.98	H
c	36.9	43.1	8.36	1.97	H
d	38.2	41.7	4.20	1.98	H
e	37.6	40.3	3.00	1.98	H
f	42.6	44.6	2.37	2.00	H
g	47.3	42.6	-5.04	-1.98	L
h	37.2	35.3	-2.96	-1.98	L
i	44.3	42.7	-2.01	-1.97	L
j	46.5	46.2	-0.36	-1.98	-
Location II: Northbound Cars					
a	54.1	55.3	1.49	1.97	-
b	50.5	48.8	-2.17	-1.97	L
f	55.2	60.7	7.39	1.97	H
g	54.8	59.5	5.17	1.97	H
h	49.4	50.0	0.75	1.97	-
i	42.9	40.5	-3.05	-1.97	L
j	44.2	40.3	-3.95	-1.97	L
Location II: Southbound Cars					
a	54.7	55.2	0.56	1.97	-
b	52.8	52.0	-0.95	-1.97	-
c	50.9	52.7	2.54	1.97	H
d	54.8	58.1	4.36	1.97	H
e	56.1	61.9	6.54	1.97	H
j	38.9	36.7	-2.85	-1.97	L

DB: Daytime-Before
 DA: Daytime-After
 H: Significantly higher
 L: Significantly lower

TABLE 14
TESTS ON DIFFERENCES BETWEEN NIGHTTIME MEANS

Station	Mean Speeds by Condition (mph)			NB-NAD Comparison		NB-NAI Comparison		NAD-NAI Comparison			
	NB	NAD	NAI	t _o	t _c	Test	Result	t _o	t _c	Test	Result
Location I: Northbound Cars											
a	56.5	57.9	58.5	1.53	1.97	-	H	0.74	1.97	-	H
b	49.2	50.4	54.1	1.66	1.97	-	H	4.89	1.97	-	H
c	44.0	42.4	45.7	-2.26	-1.97	L	H	4.48	1.97	-	H
d	40.0	41.1	41.4	1.21	1.97	-	H	0.32	1.97	-	H
e	34.8	34.3	39.1	-0.79	-1.97	-	H	7.84	1.97	-	H
f	46.4	48.0	48.9	3.06	1.97	H	H	1.55	1.97	-	-
g	51.9	55.2	54.4	3.73	1.97	H	H	-1.03	-1.97	-	-
i	52.3	56.1	55.6	4.04	1.97	H	H	-0.51	-1.97	-	-
j	55.2	55.7	56.8	0.52	1.97	-	-	1.20	1.97	-	-
Location I: Southbound Cars											
a	53.1	55.2	56.7	2.67	1.97	H	H	2.08	1.97	H	H
b	45.5	46.2	52.4	0.92	1.97	-	H	7.99	1.97	H	H
c	37.8	40.7	45.1	4.82	1.97	H	H	7.51	1.97	H	H
d	40.2	38.1	42.1	-2.74	-1.97	L	H	5.13	1.97	H	H
e	32.6	33.5	35.3	1.34	1.97	-	H	2.85	1.97	H	H
f	46.0	47.3	44.8	2.46	1.97	H	-	-4.17	-1.97	L	L
g	54.6	55.1	52.2	0.50	1.97	-	L	-3.27	-1.97	-	-
h	32.2	33.9	33.2	2.26	1.97	H	H	-1.04	-1.97	-	-
i	49.8	52.8	51.7	3.34	1.97	H	H	-1.36	-1.97	-	-
j	50.9	53.6	51.7	3.71	1.97	H	-	-2.28	-1.97	L	L

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TABLE 14 (continued)

Station	Mean Speeds by Condition (mph)		NB-NAD Comparison		NB-NAI Comparison		NAD-NAI Comparison		
	NB	NAD	NAI	t _o	t _c	Test	Result	Test	Result
Location I: Northbound Trucks									
a	49.3	48.5	52.2	-1.10	-1.97	-	3.80	1.98	H
b	43.9	45.1	49.8	1.57	1.97	-	6.67	1.98	H
c	43.2	42.9	46.6	-0.32	-1.97	-	3.42	2.00	H
d	41.2	41.8	43.1	0.75	1.97	-	2.24	1.97	H
e	38.5	37.5	41.9	-1.15	-1.98	-	3.85	1.98	H
f	41.8	39.5	42.9	-2.65	-1.97	L	1.13	1.97	H
g	48.1	47.3	47.5	-1.27	-1.97	-	-0.75	-1.97	-
i	46.0	44.2	48.8	-1.96	-1.98	-	3.00	1.98	H
j	46.0	46.9	55.8	0.80	2.00	-	8.70	2.00	H
Location I: Southbound Trucks									
a	43.5	41.9	45.2	-2.42	-1.97	L	2.34	1.97	H
b	38.5	37.9	43.2	-1.04	-1.97	-	6.94	1.97	H
c	36.1	37.9	43.3	2.77	1.97	H	8.56	1.97	H
d	38.4	37.9	39.9	-0.71	-1.97	-	2.02	1.97	H
e	36.3	37.4	36.3	1.51	1.97	-	0.00	1.97	-
f	42.7	42.1	41.2	-1.10	-1.97	-	-1.90	-1.97	-
g	48.1	48.5	46.8	0.65	1.97	-	-1.87	-1.97	L
h	34.6	37.5	34.2	3.33	1.98	H	-0.48	-1.97	L
i	42.2	40.1	42.4	-2.85	-1.97	L	0.27	1.97	H
j	44.3	42.4	44.7	-2.96	-1.97	L	0.61	1.97	H

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TABLE 14 (continued)

Station	Mean Speeds by Condition (mph)		NB-NAD Comparison Test		NB-NAI Comparison Test		NB-NAI Comparison Result		NAD-NAI Comparison Test		NAD-NAI Comparison Result	
	NB	NAD	NAI	t_o	t_c	t_o	t_c		t_o	t_c		
Location II: Northbound Cars												
a	53.5	54.6	53.1	1.56	1.97	-	-0.36	-1.97	-1.78	-1.97	-	-
b	47.8	51.9	47.4	4.93	1.97	H	-0.46	-1.97	-5.40	-1.97	L	L
f	56.9	55.9	58.6	-1.54	-1.97	-	1.75	1.97	3.14	1.97	H	H
g	52.9	51.1	53.4	-2.25	-1.97	L	0.53	1.97	2.88	1.97	H	H
h	45.6	48.9	45.8	3.67	1.97	H	0.28	1.97	-3.88	-1.97	L	L
i	38.5	41.0	40.7	2.97	1.97	H	2.59	1.97	-0.38	-1.97	-	-
j	39.7	40.4	38.1	0.73	1.97	-	-1.98	-1.97	-3.13	-1.97	L	L
Location II: Southbound Cars												
a	51.6	54.3	52.7	2.82	1.97	H	1.23	1.97	-1.89	-1.97	-	-
b	48.1	52.4	48.8	4.16	1.97	H	0.77	1.97	-3.76	-1.97	L	L
c	46.3	49.3	49.6	3.35	1.97	H	3.50	1.97	0.35	1.97	-	-
d	53.4	52.3	57.2	-1.50	-1.97	-	4.35	1.97	6.18	1.97	H	H
e	53.5	55.9	58.1	2.89	1.97	H	5.02	1.97	2.60	1.97	H	H
j	37.2	37.0	36.5	-0.26	-1.97	-	-0.94	-1.97	-0.94	-1.97	-	-

NB: Night-before

NAD: Night-after-delineation

NAI: Night-after-illumination

H: Significantly higher

L: Significantly lower

TABLE 15
TESTS ON CHANGES IN DAYTIME VARIANCES

Two-sided test; $\alpha = 0.05$					
Station	Standard Deviations by Condition (mph)		Test		Result
	DB	DA	F _O	F _C	
Location I: Northbound Cars					
a	6.7	5.4	1.50	1.40	L
b	5.7	6.6	1.34	1.37	-
c	5.3	4.8	1.22	1.34	-
d	5.7	4.9	1.35	1.39	-
e	6.3	4.6	1.92	1.41	L
f	5.2	5.9	1.30	1.40	-
g	6.4	6.2	1.07	1.41	-
i	7.6	7.7	1.01	1.36	-
j	7.2	6.8	1.13	1.39	-
Location I: Southbound Cars					
a	6.4	6.3	1.04	1.41	-
b	5.8	5.7	1.04	1.36	-
c	4.9	5.0	1.04	1.34	-
d	5.9	4.9	1.45	1.43	L
e	5.1	4.8	1.11	1.41	-
f	5.9	4.9	1.42	1.41	L
g	6.1	6.6	1.16	1.48	-
h	4.6	4.3	1.12	1.37	-
i	6.8	6.9	1.04	1.34	-
j	7.0	6.7	1.10	1.41	-
Location I: Northbound Trucks					
a	5.3	5.3	1.02	1.69	-
b	2.8	5.2	3.40	2.14	H
c	5.3	6.1	1.27	1.67	-
d	5.1	4.5	1.28	1.77	-
e	3.1	5.3	2.92	2.27	H
f	5.0	6.5	1.68	1.80	-
g	4.9	5.0	1.05	1.92	-
i	4.8	5.2	1.18	1.86	-
j	4.1	5.8	2.01	1.91	H

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TABLE 15 (continued)

Station	Standard Deviations by Condition (mph)		Test		Result
	DB	DA	F _O	F _C	
Location I: Southbound Trucks					
a	3.6	4.2	1.36	1.69	-
b	4.4	3.4	1.66	1.72	-
c	4.3	3.9	1.19	1.66	-
d	4.4	4.5	1.04	1.69	-
e	4.5	4.7	1.09	1.77	-
f	4.9	4.1	1.42	1.70	-
g	5.0	4.5	1.21	1.72	-
h	5.1	4.9	1.10	1.72	-
i	4.5	4.6	1.04	1.66	-
j	4.7	3.6	1.70	1.69	L
Location II: Northbound Cars					
a	8.2	6.0	1.85	1.38	L
b	7.5	5.9	1.62	1.37	L
f	6.7	6.3	1.15	1.39	-
g	7.1	7.7	1.17	1.42	-
h	7.1	7.0	1.02	1.37	-
i	6.7	7.1	1.11	1.39	-
j	8.3	6.2	1.77	1.47	L
Location II: Southbound Cars					
a	8.0	6.0	1.79	1.39	L
b	7.0	7.2	1.07	1.39	-
c	6.5	6.4	1.04	1.36	-
d	7.8	7.2	1.18	1.31	-
e	8.7	6.0	2.07	1.39	L
j	6.3	4.9	1.67	1.46	L

DB: Day-before

DA: Day-after

H: Significantly higher

L: Significantly lower

TABLE 16
TESTS ON CHANGES IN NIGHTTIME VARIANCES

Station	Standard Deviations		NB-NAD Comparison		NB-NAI Comparison		NAD-NAI Comparison	
			Test	Result	Test	Result	Test	Result
NB	NAD	NAI	F _O	F _C	F _O	F _C	F _O	F _C
Location I: Northbound Cars								
a	6.9	7.1	1.06	1.43	-	-	1.14	1.36
b	5.9	6.0	1.04	1.43	-	-	1.04	1.43
c	5.3	6.3	1.42	1.41	H	-	1.14	1.41
d	6.2	6.4	1.07	1.48	-	L	1.64	1.49
e	5.2	4.4	1.40	1.44	-	-	1.35	1.43
f	7.0	5.5	1.62	1.26	L	L	1.00	1.36
g	7.2	7.2	1.00	1.40	-	-	1.08	1.40
i	7.2	8.5	1.40	1.39	H	-	1.53	1.40
j	8.0	8.1	1.03	1.39	-	-	1.24	1.40
Location I: Southbound Cars								
a	6.9	7.1	1.12	1.39	-	-	1.12	1.36
b	5.6	5.6	1.00	1.47	-	-	1.08	1.48
c	5.0	4.7	1.13	1.41	-	-	1.20	1.40
d	4.9	5.9	1.45	1.48	-	-	1.33	1.48
e	5.3	4.9	1.17	1.45	-	-	1.15	1.43
f	6.8	5.7	1.42	1.27	L	L	1.09	1.36
g	7.6	8.3	1.19	1.42	-	-	1.54	1.40
h	4.4	5.7	1.68	1.52	H	-	2.00	1.50
i	8.1	7.0	1.34	1.39	-	-	1.05	1.37
j	7.2	7.3	1.03	1.32	-	-	1.03	1.38

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TABLE 16 (continued)

Station	Standard Deviations		NB-NAD Comparison		NB-NAI Comparison		NAD-NAI Comparison	
	NB	NAD	NAI	F _O	F _C	Test Result	Test Result	Test Result
Location I: Northbound Trucks								
a	4.4	3.8	3.9	1.34	1.65	-	1.29	1.68
b	4.6	4.3	4.7	1.14	1.61	-	1.03	1.72
c	3.5	4.9	5.0	1.96	1.85	H	2.06	1.91
d	5.2	4.6	5.4	1.28	1.60	-	1.08	1.54
e	3.5	5.0	5.0	2.04	1.75	H	2.06	1.78
f	5.8	5.8	5.8	1.00	1.52	-	1.00	1.62
g	4.9	3.8	4.6	1.66	1.49	L	1.16	1.66
i	3.9	5.3	5.7	1.85	1.73	H	2.11	1.71
j	4.5	4.7	5.2	1.09	2.03	-	1.33	1.98
Location I: Southbound Trucks								
a	4.4	4.3	3.9	1.05	1.52	-	1.29	1.63
b	4.2	4.3	3.9	1.00	1.45	-	1.19	1.61
c	4.9	4.3	4.7	1.30	1.47	-	1.11	1.65
d	4.8	4.5	4.3	1.14	1.53	-	1.24	1.60
e	4.7	4.5	4.7	1.09	1.55	-	1.00	1.66
f	5.3	4.5	4.3	1.39	1.35	L	1.52	1.57
g	4.0	4.6	3.9	1.32	1.40	-	1.07	1.65
h	5.3	3.9	4.0	1.85	1.69	L	1.76	1.63
i	4.1	4.8	5.0	1.37	1.58	-	1.49	1.60
j	3.8	4.2	4.4	1.22	1.56	-	1.33	1.61

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TABLE 16 (continued)

Station	Standard Deviations		NB-NAD Comparison		NB-NAI Comparison		NB-NAD Comparison		NB-NAI Comparison		NAD-NAI Comparison	
	NB	NAD	NAI	F _O	F _C	Test	Result	F _O	F _C	Test	Result	Test
Location II: Northbound Cars												
a	9.1	7.6	7.2	1.43	1.38	L	-	1.58	1.42	L	-	1.11
b	6.7	7.1	7.3	1.12	1.40	-	-	1.18	1.42	-	-	1.05
f	7.8	8.6	7.7	1.22	1.38	-	-	1.04	1.42	-	-	1.25
g	7.6	7.8	8.2	1.05	1.35	-	-	1.15	1.42	-	-	1.09
h	6.8	7.7	6.3	1.28	1.42	-	-	1.15	1.43	-	-	1.48
i	6.6	7.6	6.8	1.33	1.40	-	-	1.05	1.45	-	-	1.25
j	5.9	7.4	5.4	1.57	1.48	H	-	1.18	1.48	-	-	1.86
Location II: Southbound Trucks												
a	8.2	8.3	6.4	1.02	1.39	-	-	1.66	1.41	L	-	1.70
b	8.9	8.9	7.2	1.00	1.38	-	-	1.53	1.40	L	-	1.53
c	8.0	7.6	6.9	1.11	1.36	-	-	1.34	1.42	-	-	1.21
d	8.6	8.3	6.9	1.07	1.27	-	-	1.54	1.36	L	-	1.45
e	9.0	8.5	7.5	1.12	1.30	-	-	1.44	1.36	L	-	1.28
j	6.6	5.4	5.0	1.49	1.42	L	-	1.76	1.46	L	-	1.18

NB: Night-before

NAD: Night-after-delineation

NAI: Night-after-illumination

H: Significantly higher

L: Significantly lower

